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Volume V—Machine Monitoring and Control System

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Pulse Sciences, Inc.
600 McCormick Street
San Leandro, CA 94577

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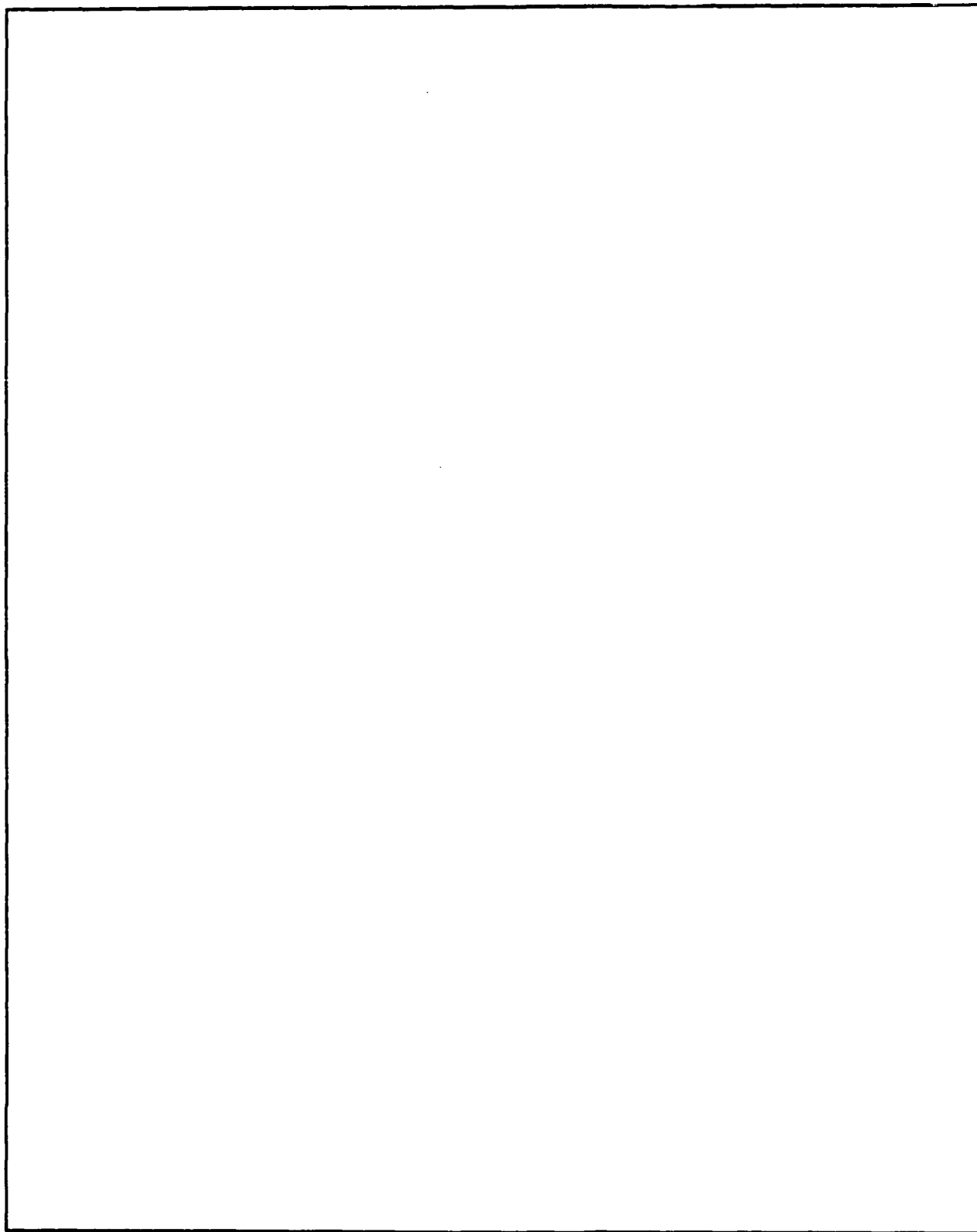
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CONVERSION TABLE

Conversion factors for U.S. customary
to metric (SI) units of measurement

To Convert From	To	Multiply By
angstrom	meters (m)	1.000 000 X E-10
atmosphere	kilo pascal (kPa)	1.013 25 X E + 2
bar	kilo pascal (kPa)	1.000 000 X E + 2
barn	meter ² (m ²)	1.000 000 X E-28
British Thermal unit (thermochemical)	joule (J)	1.054 350 X E + 3
calorie (thermochemical)	joule (J)	4.184 000
cal (thermochemical)/cm ²	mega joule/m ² (MJ/m ²)	4.184 000 X E-2
curie	giga becquerel (GBq)*	3.700 000 X E + 1
degree (angle)	radian (rad)	1.745 329 X E-2
degree Fahrenheit	degree kelvin (K)	$T_K = (t^{\circ}F + 459.67)/1.8$
electron volt	joule (J)	1.602 19 X E-19
erg	joule (J)	1.000 000 X E-7
erg/second	watt (W)	1.000 000 X E-7
foot	meter (m)	3.048 000 X E-1
foot-pound-force	joule (J)	1.355 318
gallon (U.S. liquid)	meter ³ (m ³)	3.785 412 X E-3
inch	meter (m)	2.540 000 X E-2
jerk	joule (J)	1.000 000 X E + 9
joule/kilogram (J/Kg) (radiation dose absorbed)	Gray (Gy)**	1.000 000
kilotons	terajoules	4.183
kip (1000 lbf)	newton (N)	4.448 222 X E + 3
kip/inch ² (ksi)	kilo pascal (kPa)	6.894 757 X E + 3
ktap	newton-second/m ² (N-s/m ²)	1.000 000 X E + 2
micron	meter (m)	1.000 000 X E-6
mill	meter (m)	2.540 000 X E-5
mile (international)	meter (m)	1.609 344 X E + 3
ounce	kilogram (kg)	2.834 952 X E-2
pound-force (lbf a voirdupois)	newton (N)	4.448 222
pound-force inch	newton-meter (N.m)	1.129 848 X E-1
pound-force/inch	newton/meter (N/m)	1.751 268 X E + 2
pound-force/foot ²	kilo pascal (kPa)	4.788 026 X E-2
pound-force/inch ²	kilo pascal (kPa)	6.894 757
pound-mass (lbm a voirdupois)	kilogram (kg)	4.535 924 X E-1
pound-mass-foot ² (moment of inertial)	kilogram-meter ² (kg.m ²)	4.214 011 X E-2
pound-mass/foot ³	kilogram/meter ³ (kg/m ³)	1.601 846 X E + 1
rad (radiation dose absorbed)	Gray (Gy)**	1.000 000 X E-2
roentgen	coulomb/kilogram (C/kg)	2.579 760 X E-4
shake	second (s)	1.000 000 X E-8
slug	kilogram (kg)	1.459 390 X E + 1
torr (mm Hg. 0°C)	kilo pascal (kPa)	1.333 22 X E-1

*The becquerel (Bq) is the SI unit of radioactivity: Bq = 1 event/s.

**The Gray (Gy) is the SI unit of absorbed radiation.

PREFACE

This volume is one of five volumes reporting the Aurora Upgrade Program conducted by Pulse Sciences, Inc. (PSI) under Contract No. DNA001-85-C-0140 from the Defense Nuclear Agency (DNA) for the Harry Diamond Laboratories (HDL). The five volumes are entitled:

- Volume 1: Multipulse Modifications and Tests
- Volume 2: High Power Microwave Environment
- Volume 3: Gradient B Drift Transport Risetime Sharpening
- Volume 4: Diverter Switch Pulse Shortening
- Volume 5: Machine Monitoring and Control System

This work, which included PSI assisting HDL in reviewing and integrating associated Aurora Upgrade efforts being performed by other organizations, was performed over the period February 1985 through March 1988.

The DNA CTM was chronologically, Col. Jay Stobbs, Walt Jourdan, and Capt. Paul Filios. Dr. Jack Agee was the HDL technical and administrative authority. The program was managed by Philip Champney.

Volume 5 describes the Machine Monitoring and Control System (MMC) designed and installed to assist in the operation of Aurora by simplifying the setup and automating the collection and archiving of data related to its operation.

Al Poirier and Bill Lilley, together with the Aurora operation and maintenance team and the data acquisition team, gave PSI considerable assistance during the entire modification and test periods. PSI wishes to express appreciation for the extremely helpful HDL participation.

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TABLE OF CONTENTS

Section	Page
CONVERSION TABLE	iii
PREFACE	iv
FIGURES	vii
1 INTRODUCTION	1
2 DESIGN OF THE MMC SYSTEM	2
2.1 OPERATING SEQUENCE	2
2.2 SYSTEM LAYOUT	4
2.3 SIGNAL HARDWARE	4
2.4 CAMAC HARDWARE	6
2.5 COMPUTER HARDWARE	9
2.6 SOFTWARE SUBSYSTEM	9
2.7 SUMMARY	12
3 MMC SOFTWARE	13
3.1 INTRODUCTION	13
3.2 THE STRUCTURE OF MMC	13
3.3 SIGNAL NAME CONVENTIONS	18
4 FAST SIGNAL SUBSYSTEM	20
4.1 SUBSYSTEM ARCHITECTURE	20
4.2 SIMULATOR INTERFACE	23
4.3 ANALOG SIGNALS	25
4.4 TRIGGER AND GATING PULSES	27
4.5 TIMING MEASUREMENTS	41
4.6 ANALOG MULTIPLEXERS	41
4.7 INSTALLATION	44
4.8 CALIBRATION	46
4.9 SUMMARY	50
5 SLOW SIGNAL SUBSYSTEM	52
5.1 SLOW SIGNAL HARDWARE OVERVIEW	52
5.2 GAS PRESSURE MEASUREMENT HARDWARE DESCRIPTION	53
5.3 MARX CHARGING MONITORING SYSTEM HARDWARE DESCRIPTION	55
5.4 BLUMLEIN OIL SWITCH POSITION MONITORING HARDWARE	57
5.5 VACUUM MONITORING HARDWARE DESCRIPTION	58

TABLE OF CONTENTS (Concluded)

Section		Page
5.6	TAG AND TRIGGER MARX CHARGE VOLTAGE MONITORS	58
5.7	DIGITAL/LOGICAL SIGNALS	59
5.8	SIGNAL TRANSMISSION SYSTEM DESCRIPTION	59
5.9	SLOW SIGNAL CAMAC CABINET (#1) DESCRIPTION	59

FIGURES

Figures	Page
3.1 MMC flow between screens	14
3.2 Diagram of the MMC tasks	15
3.3 Parts of a signal name	18
4.1 Block diagram of fast signal subsystem	22
4.2 Generation of trigger pulses used to synchronize fast signal subsystem and simulator	24
4.3 25:1 signal tapoff	26
4.4 Circuit diagram for signal conditioning	28
4.5 Architecture of trigger generator module signals	31
4.6 Timing tree for normal firing of simulator	32
4.7 Timing tree for a prefire of simulator that is detected only on pulse charge signal associated with Blumlein A	34
4.8 Diagram for normal timing signals	36
4.9 Diagram for prefire timing signals	40
4.10 Timing and simulator signals associated with Blumlein B	42
4.11 Diagram for analog multiplexing signals	45
4.12 ADC response	48
5.1 Transducer calibration circuit	54
5.2 Aurora slow signal transmission system	60
5.3 Aurora CAMAC cabinet #1 block diagram	61
5.4 Aurora slow analog signal conditioning board schematic	63
5.5 Aurora input/output register filter board schematic	64
5.6 Junction A chassis	65

SECTION 1

INTRODUCTION

The objectives for the Aurora Machine Monitoring and Control (MMC) task of DNA Contract DNA 001-85 0-0140 were to design, develop, fabricate, and install a monitor and control system that would significantly increase the amount and quality of the operational information obtained from the Aurora simulator, and to assist the Aurora staff in the operation of the simulator. The accomplishment of these objectives required the design and acquisition of a wide range of hardware and the development of a substantive software package as described below.

Initially this task was called the Computer Data Acquisition (CDA) task. Subsequently at the request of Aurora MDC personnel, the task was renamed the Machine Monitoring and Control (MMC) task.

At the time that the MMC task was started, the Aurora simulator was in need of upgrading and refurbishment of a number of its sensor systems. In particular, many of the gas pressure sensors and gauges were either inoperative or inaccurate. The Aurora staff also desired replacement of the high vacuum gauges as well as additional gauges. These requirements were to be addressed in the MMC task.

Also, it was hoped that a software package developed for DNA by The BDM Corporation could be used directly or adapted to meet the software requirements of the MMC task. An examination of the limited documentation available for the package, the source code listing, and the "operation"

of the package then being installed at NSWC indicated that it could not satisfy the requirements for a system as complex as the Aurora simulator without extensive modification. Such a modification of an unfamiliar code would be more difficult than writing a new package specifically for the Aurora simulator.

When the MMC task was initiated, orders had already been placed by HDL for some CAMAC and computer related hardware. This hardware had been selected specifically to be compatible with the BDM software. In addition, HDL had a computer, tape deck, and hard disk available that was also compatible with the BDM system. The selection of this hardware had some unfortunate consequences as described in Section 4.4.2.

In June 1985, one of the authors (Lee Schlitt) visited HDL to discuss the requirements and desired features of the MMC system with members of the HDL staff. Following this visit, a conceptual design of the hardware and software systems was performed, and a report was submitted to HDL for approval and comments. A second visit to HDL was made to discuss the conceptual design and led to its approval with some minor modifications that were not formally documented in an amended report. The conceptual design is described in of Section 2.

The software subsystem is discussed in Section 3. Sections 4 and 5 describe the acquisition systems for transient data signals and dc, respectively.

SECTION 2

DESIGN OF THE MMC SYSTEM

2.1 OPERATING SEQUENCE.

The design of the MMC system is largely dictated by the sequence of steps that is necessary to operate the Aurora simulator and the information that is needed in order to fire it and to ascertain whether it performed as intended. The sequence is divided into three phases: setup, charging and firing, and post-shot data acquisition.

2.1.1 Setup.

During the setup phase of the sequence the simulator operator must determine all of the simulator parameters that are necessary to satisfy the shot requirements, measure the present values of each of the parameters, and adjust them to bring them within an allowable tolerance of the desired values. There are nearly fifty such parameters for the Aurora simulator. These include the charging voltage setpoints for each of the Marx generators, the gas pressures for the spark gap switches, aft and midplane electrode spacings for the Blumlein oil switches, vacuum pressures in the tube and anode regions, and the timing delays between trigger pulses for the Marx generators and the Blumlein oil switches. Each of the parameters has a "nominal" value and a tolerance associated with it.

There are a total of eight voltages involved in dc charging the Marx generators (dual polarities for each of the four generators). In order to be consistent with common usage, four voltage setpoints are specified as the total charging voltage across each of the generators. These setpoints determine when charging is complete and should be interrupted for each generator.

There are eighteen active gas pressures which must be set prior to each shot. These include pressures for four Trigger Amplifier Gaps (TAG), two Trigger Marx (TM) generators, four Main Marx generators, four Trigger Isolation Gaps (TIG), and four Master Switches. In addition, one gas reservoir pressure is routinely monitored, but not set.

There are eight Blumlein oil switch electrode spacings. Each of the four oil switches has two electrodes (aft and midplane).

There are eight vacuum pressures that are monitored but not set. One gauge is located at each of the four tube stacks, and one near each anode.

In normal (single pulse) operation, there is only one delay that is set. It is the delay between the electrical pulse which is sent to TAG1 and leads to the triggering of the main Marx generators, and the electrical pulse that is sent to TAG2 and leads to the triggering of the Blumlein oil switches that generate the simulator output pulses. In the multipulse (two) mode of operation, there are three delays. Two delays are required for the purpose just described (one for each pair of TAGs 1,2 and 3,4). A third delay must be set between the trigger pulses for TAGs 1 and 3 which determines the temporal spacing between the two simulator radiation pulses.

Once the operator has set all of the simulator parameters, the machine is ready to be fired; assuming, of course, that all of the safety procedures have been followed and that the user is also ready.

2.1.2 Charge/Fire.

The typical procedure for charging and firing the simulator involves several steps. The first step is usually to scan all of the available instruments to determine if the parameters have been set and have retained their desired values. This preshot review is difficult to perform on the Aurora simulator without the MMC system since most of the instruments are multiplexed. That is, one meter is switched to read many different parameters. As a result, only the most critical are reviewed.

Following the preshot review, the charging step is initiated. The most critical phase of the operating sequence is the time between the start of Marx charging and firing of the simulator. During this time, the operator monitors as much of the simulator data as possible giving particular attention to the charging supply output voltage and current. It is not reasonable for the operator to monitor eight different charge voltages and eight different charge currents with analog meters even if they were available.

Once the simulator has been charged, clamps on the outputs of the Marx are withdrawn and the op-

erator checks as much information as possible before giving permission to fire. This preshot review is performed as quickly and completely as possible.

After the simulator has been fired, the operator checks as much information as possible to determine if the shot was normal or anomalous. The consequences of many types of failures can be mitigated by prompt action from the operations staff. Elapsed time from the shot is critical during this post-shot review process.

2.1.3 Data Recording.

Two types of data records of simulator performance on a shot are usually needed. One is a permanent record of all available information which can be examined at a later date in order to look for trends, refresh memories, or check on specific details. This "archive" need not be printed as long as the information is available. The second record involves information that the operations staff needs to examine in detail following a shot to determine if there were any problems that require correcting or any trends evident that require adjustments to the simulator parameters for subsequent shots. This post-shot examination frequently involves comparisons between different signals from the same shot, or the same signal on a previous shot. This almost requires a printed document to be prepared.

2.1.4 Requirements and Constraints on the MMC System.

Most of the requirements and constraints for the MMC system are contained either explicitly or implicitly in the operating sequence described in Section 2.1 above. However, there are several important constraints that are not. Specifically, Aurora is a "user facility" which sells time to its customers. It is extremely important, that the MMC system not interfere with the customer's use of the facility. This implies a requirement for a high degree of reliability in the MMC system. While the system has been designed and constructed to be as reliable as possible without redundancy, only operational experience can demonstrate its compliance with this requirement. In order to eliminate the risk of interference with the customer, the MMC system was designed so that the simulator can be operated independent of MMC. That is, no parts of the existing controls and diagnostics were removed or rendered inoperable by the installation of the MMC system. (It is hoped that the MMC system

will prove to be sufficiently reliable that much of the existing control and diagnostic system can ultimately be replaced by the MMC system.)

In order to facilitate system maintenance and enhance operational reliability, "hardwired" software and hardware were avoided as much as possible. That is, the system was designed with spare hardware channels and interchangeable parts where possible. The software is as general as possible and permits the reassignment or deactivation of signal channels without alterations to the code itself. Thus the failure of a cable, a component, a measuring channel, or even a CAMAC module can be circumvented by reassignment or deactivation without disabling the MMC system.

Good engineering practice required that the inputs to the MMC system be protected from transients associated with firing of the simulator, and that provisions be made for simple calibration of the hardware where possible.

The operations staff has little experience with computers. Therefore, the MMC system was made "user friendly" and requires as little knowledge of computers for its routine operation as possible. This suggested that the system be "menu driven" with the operator making selections from a displayed list of options, rather than entering memorized commands to perform the tasks that are desired.

The first requirement that is implicit in the operating sequence described above, was that manual data entry had to be avoided as much as possible. The sheer number of setup parameters with their associated nominal values and tolerances virtually precluded manual entry. The possible variations in these parameters due to desired variations in simulator output and changes in component performance precluded imbedding a fixed set of parameters within the MMC system software. Therefore, these parameters must be read from a data file which describes a particular machine configuration or setup. The operator can then simply select the data file that describes the type of shot or operating conditions desired and the parameter nominal values and tolerances are known to the software and displayed to the operator as appropriate.

For those parameters for which the operator must bring the measured value into compliance with the nominal value, the operator must have both values available as well as the permitted tolerance. A simple mechanism for determining

compliance had to be available. (The MMC system uses the colors green, yellow, and red for this purpose.)

A preshot review display is available which indicates compliance between nominal and measured values of all simulator parameters that are determined before Marx charging is initiated.

During charging, all eight charging voltages and all eight charging currents are displayed in a fashion which permits assimilation of the information by the operator and updated continuously. (The MMC system uses a color-coded set of bar indicators for this purpose.)

Following a shot as many measurements of simulator parameters and shot output signals as possible are made as quickly as possible and displayed to the operator.

A shot document should be prepared following each shot and contains the most useful information on preshot and post-shot conditions, the Marx charging history(ies), and simulator outputs. All of the measured data can be stored in an archive data file with a mechanism for subsequent retrieval.

2.2 SYSTEM LAYOUT.

Most of the equipment associated with the MMC system is located in five racks or cabinets in the simulator control room. One free standing equipment rack houses the operator's console and direct readouts for the vacuum gauges, Blumlein oil switch electrodes, and the diverter electrodes (not a part of the MMC system). The tap-off chassis for the fast signal subsystem replaces the simulator patch panel in one of the control racks. The remaining control room hardware, with the exception of the laser printer, is housed in three RFI-tight cabinets. One houses the computer, its peripherals, and the serial highway driver for the CAMAC system. Another houses the CAMAC equipment for the slow signal subsystem and the junction chassis and signal conditioning for that subsystem. The remaining cabinet houses the CAMAC equipment and signal conditioning for the fast signal subsystem.

The remaining equipment is distributed throughout the simulator bay. It is limited to slow signal sensors, their associated power supplies, RFI-tight enclosures for collecting cables from the sensors, and the cables which deliver the signals to the control room.

2.3 SIGNAL HARDWARE.

The simulator signals monitored by the MMC system fall into three classes: "slow" signals, "fast" signals, and a very limited number of "logic" signals. The slow signals are "quasi-dc" varying, at most, over a time scale of several seconds. Signals monitoring gas pressures and electrode positions fall into this class. The fast signals result from the firing of the simulator. They range from 0.05 to 5 μ s in length and all are delivered to the control room within 10 μ s of triggering the simulator. The outputs from the pulse charge voltage monitors and tube current shunts fall into this class. The logic signals are used for binary control functions. At the present time, they are used only for signals taken from the simulator controls and used to synchronize software to simulator operations during the charging and firing of the simulator.

Hardware treatment of the three classes is very different. Nearly all of the slow signal channels involved the installation of new sensors at the simulator, and new cabling running from the simulator to the control room. Much of the complexity of the slow signal subsystem of the MMC system is external to the control room. By contrast, no new sensors were installed for the fast signal subsystem. All of the fast signals are sampled within the control room from the existing cabling. Nearly all of the complexity associated with the fast signal subsystem resides within the RFI-tight enclosure that houses the CAMAC hardware associated with the subsystem. The logic signals originate within the control room and are the simplest part of the system.

2.3.1 Sensors.

New sensors were provided for measuring all gas pressures associated with spark gaps in the simulator. The units selected are solid state devices which convert absolute pressure directly into an electrical signal. These transducers are all housed within a single RFI-tight enclosure that is mounted below the Marx tank of the simulator near the existing mechanical gauges. Small diameter nylon tubing was used to connect the new transducers to the existing gas distribution system. This tubing provides electrical isolation and dampens pressure transients associated with firing the simulator. The enclosure contains the power supply required by the transducers. Each transducer is connected to a common manifold through an electrically activated valve which permits the simultaneous calibration of all of the transducers. The manifold pressure is measured

with a single precision mechanical gauge. There is no provision for monitoring these transducers except through the MMC system.

New sensors to monitor the dc charging of the Marx were installed in the Marx disconnect box. Eight precision, high voltage resistor chains are used to measure the charging voltages for each polarity and each Marx generator separately. Eight magnetic amplifier current transducers were installed to measure the charging current for each polarity and Marx generator. These units do not connect directly to the high voltage power supply leads but measure the magnetic field produced by current flowing in the leads. The current transducers were ultimately mounted in RFI enclosures within the disconnect box, and were equipped with isolating relays and other components to protect them from transients associated with firing of the simulator. The power supply for the current transducers is mounted in an enclosure on the lid of the disconnect box.

New linear potentialities were installed to monitor the positions of the Blumlein oil switch electrodes. These potentiometers were mounted on the slave cylinders of the existing electrode positioning system. This was considerably easier than modifying the existing electrical measuring system and did not interfere with the existing system in any way. The precision power supply that serves as the reference for the linear potentiometers is mounted in an RFI enclosure that also serves as the junction box for all of the slow signal subsystem cabling below the Marx generator tank. These potentiometers are read by both the MMC system and by an independent system of digital gauges.

A proximity detection system was developed for the Blumlein oil switch electrodes. Its purpose was to detect contact between the aft and mid-plane electrode of each switch. This was necessary because axial separation between the inner and intermediate conductors can change as the machine is filled with oil or fired. The system provides an automated means of calibrating the electrode position after filling or between shots. This portion of the MMC system was not installed although both the hardware and software was developed.

New vacuum gauges were installed on each of the Blumlein vacuum systems. Gauges were installed near the tubes and near the anodes of each line. Cold cathode gauges were selected because of their inherent ruggedness and low

coupling to electrical transients. The "remote readout" provisions of these gauges are used for monitoring by the MMC system.

Existing monitors for the trigger Marx and TAG charge voltages were used by the slow signal subsystem. The outputs from these monitors are sampled at their meters in the control room with resistive signal splitters.

2.3.2 Fast Signal Tap-offs.

The fast signals from the simulator are sampled in the Tap-off Chassis which physically replaced the simulator patch panel in the control room. The tap-off chassis provides outputs of all fast signals for use in the control room as well as providing outputs for the MMC system and the data room. Resistive splitters were selected due to the large amplitude of most of the simulator signals.

The amplitude of signals at the MMC outputs of the tap-off chassis was limited to 130 volts so that high density connectors and compact variable attenuators could be used in the subsystem. Some of the CAMAC modules used to process the fast signals require a minimum signal amplitude to operate. As a result, the amplitude of signals at the MMC outputs of the tap-off chassis must exceed 2 volts. This range of voltages is significantly less than the dynamic range of signals coming from the simulator. Thus, it was necessary to employ two different tapoff ratios in the subsystem. Forty signal channels are equipped with 25:1 tapoffs designed and fabricated by PSI employing carbon composition resistors and stripline printed circuit board techniques. These splitters can be used with signal amplitudes up to 2 kV. The remaining ten signal channels are equipped with commercially available 2:1 signal splitters for use with signals whose peak amplitude is less than 130 volts.

2.3.3 Cabling.

All new cabling was run for the slow signals acquired in the simulator bay. Except for the vacuum gauges, multiple shielded, twisted pair cables are used throughout with sizes ranging up to 26 pair. All cable is enclosed in electrical conduit or RFI-tight enclosures with the exception of short connections to the Disconnect Box and the electrode position potentiometers. The vacuum gauges use RG-59 coaxial cable due to the high voltage involved.

A variety of cable types are used within the control room for slow signals. The types include shielded twisted pair, RG-59 and RG-174 coaxial,

and ribbon. The type of cable is dictated by the type of termination required at the cable's destination. Metal shielded MS series connectors were used wherever possible.

Only two types of cable are used in the fast signal subsystem. RG-223 coaxial cable is used for the main signal paths in the tap-off chassis and for the connections between the tapoff chassis and the rest of the subsystem. RG-174 is used for all remaining connections.

2.3.4 Signal Distribution.

With the exception of the cables which service the vacuum gauges, all of the cables associated with the slow signal subsystem are collected beneath the Marx tank of and transported to the control room in a single conduit. One cable is terminated in a standard equipment rack which houses digital meters for direct readout of some of the signals. The remaining cables are terminated at the RFI cabinet which houses the CAMAC equipment for the slow signal subsystem. The signals carried by these cables are then routed through the signal conditioning circuits to two junction chassis mounted within the cabinet. Cables which are compatible with the slow signal CAMAC modules run from the junction chassis to the modules. Interconnections between the cables coming from the simulator and those going to the CAMAC modules are made by jumper wires within the junction chassis. This scheme is necessary because some of the CAMAC modules utilize a single, high density connector for all signals. The sources or destinations of these signals are distributed between different locations within the control room and simulator bay.

All of the fast signals are carried in individual coaxial cables. The splitting of each signal to drive several CAMAC modules is accomplished in the signal conditioning system described in Section 2.3.5. The signals are delivered directly to the CAMAC inputs from the signal conditioning enclosure. Additional patch panels are not used.

2.3.5 Signal Conditioning.

Signal conditioning for the slow signals is synonymous with protection from the transients associated with firing the simulator and is discussed in Section 2.3.6. The associated circuits are housed in an RFI-tight enclosure mounted within the RFI cabinet that houses the CAMAC hardware associated with the slow signal subsystem.

Signal conditioning for the fast signals involves both transient protection and a variety of other steps to make the signals compatible with the requirements of the CAMAC modules. Each type of CAMAC modules has a different set of input polarity and amplitude requirements. The maximum expected signal amplitude should be near the full scale range of each CAMAC module used so that the finite digital resolution of each module is fully utilized. Input signal amplitudes must exceed a threshold for the time to digital converters (TDCs) to function at all. In addition, each simulator signal is delivered to three or four modules for processing. All of the functions associated with signal conditioning for the fast signals are treated on plug-in printed circuit boards that are housed in an RFI-tight enclosure mounted within the RFI cabinet that houses the CAMAC equipment associated with the fast signal subsystem. These functions include overall variable attenuation and inversion for each signal, followed by splitting and further inversion or attenuation for each of the split channels as appropriate.

2.3.6 Transient Protection.

A number of steps have been taken to protect the CAMAC equipment of the MMC system and companion metering from electrical transients generated by the firing of the Aurora simulator. Where possible, sensors have been located in RFI-tight boxes. In all cases, sensor power supplies have been located in RFI-tight boxes with commercially available RFI filters on their AC lines. Entrances to the slow signal cable conduits employ commercially available multipin RFI connectors. Shielded cable is used in all applications external to the RFI cabinet that houses the slow signal CAMAC equipment. Most of the slow signal cable runs are within conduit.

Signal paths within the RFI cabinets are maintained within conduit and RFI enclosures until passage through their associated signal conditioning circuits. Signal conditioning circuits for the slow signals employ RLC filters and clamping diodes on all lines. Signal conditioning circuits for the fast signals use a single zener diode at the point where the signals are split. The voltage is negative with a magnitude of less than 4.8 volts at this point for all signals processed by the fast signal subsystem. Logic signal paths use RC filters.

2.4 CAMAC HARDWARE.

The CAMAC hardware used in the MMC system consists of data acquisition modules, timing modules, switching modules, data transfer

equipment, and crates. The MMC system generates timing signals which control the firing of the simulator. This is the only control function of the system at this time.

The data acquisition modules accept electrical signals (slow, fast, or logic), measure their characteristics, convert the results of the measurements into digital data, store the data, and deliver it to the system upon demand. Some of these modules process as many as fifty signals, and some as few as one.

The timing modules generate electrical pulses which are required by other modules and the simulator. Few of these modules interact with the software subsystem. Analog switching modules are used in the analog multiplexing system described below.

The data transfer equipment provides the link between the CAMAC modules and the MMC system computer. The Serial Highway Driver links the computer's data bus with a specific type of electrical dataway which services CAMAC equipment. This dataway is connected to Serial Crate Controllers located in each crate. Each crate contains another dataway which links its controller to each of the modules installed in the crate.

The crates provide the data link described above as well as an acceptable environment for the modules. The crates contain power supplies to satisfy the needs of each of their modules, forced air cooling for the modules, and physical mounting for the modules.

2.4.1 Crate Organization.

The data acquisition modules associated with the slow signal subsystem achieve an extremely high channel density. Some of them process as many as fifty signals and occupy only one station in a crate. By contrast, some of the transient recorders used in the fast signal subsystem process only one signal and occupy five stations in a crate. With two stations occupied by the crate controller, and one station reserved for a Dataway Display used during troubleshooting, each crate has twenty-three stations available. Thus it is not surprising that crate "real estate" is very precious in the fast signal subsystem.

Since nearly all of the hardware associated with the Aurora simulator is replicated four times (once for each Marx or each Blumlein), it would

be logical to employ four-fold replication of each type of CAMAC module in the system and use a multiple of four crates to house them. Such an approach leads to a great deal of excess capacity in the system and would require a total of eight crates. Neither the space nor the funds were available for such an approach.

All of the CAMAC modules for the slow signal subsystem are located in a single crate, and occupy only a third of the space available in the crate. This crate is mounted in an RFI cabinet which also contains the signal conditioning hardware and junction chassis for the subsystem. This crate also contains a transient recorder which would not fit into the crate space available for the fast signal subsystem.

It was originally intended that all of the fast signal subsystem except for the tap-off chassis would be contained in a single RFI cabinet which would house four CAMAC crates. When multiplexing of the transient recorder signals was limited to two per recorder, it was not possible to house all of the CAMAC modules in four crates. As a result, the transient recorder which was intended to service the radiation photodiode is located in the crate used by the slow signal subsystem.

The fast signal subsystem does not contain any signals which are explicitly referenced to the Marx generators (pulse charge signals are associated with the Blumleins). Thus it is convenient to associate one CAMAC crate with each Blumlein. The trigger amplifier gaps and trigger Marx generators can be associated with a Blumlein pair.

One approach to the subsystem architecture would be to populate each crate with identical hardware. This would greatly simplify the design and implementation of the subsystem. However, this approach was rejected because a complete complement of CAMAC modules would not fit into a single crate and would have required eight crates for the fast signal subsystem alone.

Since the multipulse mode involves only the operation of Blumlein pairs (A-B and C-D), it is reasonable to service some signals for a Blumlein pair in a single CAMAC module located in one crate in order to reduce costs and fit within a four crate system. The final architecture selected for the four crates of the fast signal subsystem (except for the photodiode) assigns two crates to Blumleins A and B, and two crates to Blumleins C and D.

2.4.2 Data Acquisition Hardware.

The slow signal subsystem employs two types of analog to digital converters (ADCs). One type continually samples all of its inputs on a rotating basis converting the measured voltage to digital data. The other type samples all of its inputs at the same time in response to a trigger from software or hardware. The second type is used to monitor Marx charging signals since computations of delivered charge are compared to charge voltage and are meaningful only if the measurements of voltage and current are made at the same time. The logical signals are included with the slow signals in system documentation. They are monitored by an Input Register which determines only whether the input voltage exceeds a threshold. They are used to monitor the states of certain simulator control signals such as Charge Complete so that software can follow the various operational steps during the charging and firing of the simulator.

There are four types of data acquisition modules in the fast signal subsystem. These are the time to digital converters (TDCs), the transient recorders (TRs), the integrating analog to digital converters (IADCs), and the peak reading analog to digital converters (PADCs). The TDCs measure the arrival times of signals. The TRs record a complete temporal history of the input signals. The IADCs integrate the input signals over a time interval determined by gate pulses which are synchronized to each signal. The PADCs measure the maximum signal amplitude which occurs during the interval for which they are gated. In addition, discriminators with computer controlled thresholds are used to convert the slow rising pulse charge signals to fast rising pulses which are generated at one half of peak amplitude.

2.4.3 Control Hardware.

The only control functions performed by the MMC system are the generation of timing pulses that are required to fire the simulator. This portion of the system is briefly described in Section 2.4.4. Hardware was fabricated and some software was developed to provide full computer control and automatic calibration of the Blumlein oil switch and diverter electrodes. These controls were to use output registers to generate On/Off signals under the direction of the computer. The input registers mentioned in Section 2.4.2 can be considered to be either control hardware or data acquisition hardware.

2.4.4 Timing Hardware.

The timing section of the fast signal subsystem consists of an Interface module, two dual gate/delay generator modules, trigger generator modules, and gate generator modules. In addition, the discriminators become a part of the timing section in the event of a simulator prefire while the clamps are being withdrawn and one or more of the Blumleins becomes charged. The interface module converts the timing signal generated by the simulator (TOIN) into the correct amplitude and polarity required by the fast signal subsystem, and converts the timing signals generated by the subsystem into the amplitudes and polarities required by the simulator. The two delay generators determine the delays between the simulator timing signals. The trigger generator modules generate pulses for the inputs of the gate generator modules and generate "trigger" and gate pulses for some of the data acquisition modules. The gate generator modules produce nearly all of the gate pulses and the remaining "trigger" pulses required by the data acquisition modules. If a simulator prefire results in charging one or more of the Blumleins to more than one-half of the expected voltage, one or more of the discriminator modules will detect the prefire and send a signal to the trigger generator modules. This results in the generation of timing signals required to service the appropriate portion of the timing section.

2.4.5 Analog Signal Multiplexing.

In order to reduce the number of expensive transient recorders necessary to service the desired number of simulator output signals, an analog multiplexing scheme has been incorporated into the fast signal subsystem. One half of the multiplexed signals are fed into commercially available analog delay lines which produce a 500 ns delay. Pairs of analog signals (one delayed and one not delayed) are delivered to adjacent inputs of an analog switch. These analog switches are internally strapped so that in each pair of inputs, one is "normally open" and one is "normally closed". Identical gate pulses are fed into each channel pair from a Gate Generator module output so that a single gate pulse switches between two analog inputs. Passive combiners are used to sum pairs of outputs thus completing the SPDT switching function.

The analog delay lines were selected when multiplexing four signals per transient recorder was under consideration. The choice was not reviewed when the number was reduced to two sig-

nals per transient recorder. The HDL staff has suggested that the delay lines be replaced with 1 μ s units which would increase the temporal window for each signal. This is an excellent suggestion and can be readily accommodated, but has not been implemented.

2.5 COMPUTER HARDWARE.

2.5.1 Description.

Most of the MMC system computer hardware is mounted in an RFI cabinet along with the Serial Highway Driver (SHD) described in Section 2.4. This equipment consists of a DEC PDP-11/44 computer, a DEC RA-80 disk drive, a tape drive, and the SHD. The SHD must be located in close proximity to the computer since the computer's data bus is routed through the unit.

A Tektronix 4107A color graphics terminal is used for the operator's console and is located in an equipment rack next to the simulator controls. A DEC LN03-plus laser printer is used to produce the Shot Document. A DEC LA-100 printer was tried in the system, but proved to be too slow.

2.5.2 Limitations.

The computer equipment was selected to be compatible with the BDM software package which was under development at the start of this program. Unfortunately, this choice had several adverse consequences. These consequences impact both the use and maintenance of the MMC system.

The PDP computer is designed for the concurrent execution of several small tasks, whereas this application requires the sequential execution of a single large task. Many compromises were made in order to fit the MMC software into this machine. The software was broken into several smaller tasks which are executed sequentially. As a result, annoying delays were introduced into the system. Also, a great deal of complexity was required in the heavily overlaid coding. The overlaid structure of MMC makes code maintenance difficult since minor changes in the code can cause overlays to exceed the available space. This may require major rearrangement of the code.

The Tektronix color terminal is an excellent terminal, but it requires a great deal of input data to generate and display even simple geometric figures. The time required to transmit the data from

the computer to the terminal severely limits the amount of information that can be displayed in "real time". This is particularly a problem during the charging of the Marx generators. In order to present a useful display of current conditions, the display should be updated at least twice a second. Many of the intended features of the Marx charging display have been disabled in order to reduce the time between updates. Even with minimum real time information displayed, the time between updates is approximately 0.8 seconds.

2.6 SOFTWARE SUBSYSTEM.

2.6.1 BDM Software.

The BDM software package has specific limitations that prevent its use in this program. The low density of its graphical displays though well matched to the speed of communication with the Tektronix terminal prevented the display of all of the information required by the operator during Marx charging. It also would have made the setting of all of the simulator parameters (particularly gas pressures) an extremely tedious and time consuming task. The requirement for manual entry of the parameters also would have made the setup of the simulator difficult and time consuming. A separate software package was required for processing data acquired by the transient recorders. While this part of the BDM package is more powerful than that presently incorporated into the software subsystem, its use as a separate package would be cumbersome. The approach to the overall problem used by the BDM package was to create or "spawn" separate tasks to perform each of the functions required for simulator operation and then executed these tasks concurrently. This approach is well matched to the capabilities of the computer, but not to the Aurora application which requires a great deal of coordination between and control of the tasks. Although it would be possible to deal with these problems by modifying the BDM software, there was virtually no documentation of the BDM package available. Therefore, a separate software package called MMC for Machine Monitor and Control was written specifically for the Aurora simulator.

2.6.2 Introduction to MMC Software.

There are two types of structures associated with the software subsystem: the logical structure which surrounds the functions that the subsystem performs, and the physical structure or organization of the subsystem. The sections that follow

describe the elements which make up the logical structure of MMC. The physical structure, which was largely dictated by the constraints of the computer hardware (see Section 2.5.2), has an impact on MMC's performance but is not described here. Details on this aspect of MMC can be found in Section 5.

There are several elements which make up the logical structure of MMC. The operator interface provides a means for the simulator operator to direct MMC's activities, modify simulator parameters, and monitor the measurements made by MMC. The MMC database provides information establishing the correspondence between computer variables and the inputs to the various CAMAC modules of the MMC system. It also contains the desired or "nominal" values for simulator parameters and the tolerances associated with these parameters. Finally, it contains the sensor sensitivity and system calibration data that is required to convert the digital data from the CAMAC hardware into the actual values which that data represents. The Shot Document is the printed record of the results of the most important measurements made by the MMC system associated with the firing of the simulator. The Archive is a detailed (computer readable) record of all of the data associated with firing of the simulator.

MMC uses these elements to assist the simulator operator in performing the sequence of steps required to set up, charge, and fire the simulator as described in Section 2.1. MMC uses menus, its database, its logical structure, and color to satisfy the constraints and requirements described in Section 2.1.

2.6.3 Operator Interface.

The simulator operator interacts with the MMC system through the Tektronix color graphics terminal. When MMC is started, it guides the operator through the sequence of steps required to set all of the simulator parameters. This is accomplished by displaying a sequence of "screens", one for each class of simulator parameter, that allow the operator to see the nominal value for each parameter, to see the present measured value of each parameter, and to alter the nominal value if desired. Colors are used to indicate the relationship between the nominal and actual values of each parameter. If the actual value is within the specified tolerance of the nominal value, then a green symbol or box is displayed. Yellow

is used when the actual value lies outside of one specified tolerance but within a second tolerance. Red is used when the actual value lies outside of the second tolerance limit. If the tolerances are set appropriately (in the database), the green-yellow-red color scheme can be used to represent OK-warning-error conditions.

Plans to allow the operator to use the MMC system to set trigger pulse time delays, Blumlein oil switch and diverter switch electrode spacings as a part of the simulator setup were abandoned due to budget constraints.

Once the operator has completed the setting of all simulator parameters, he is presented with a menu which allows him to return to any of the screens associated with a particular class of parameter or to proceed to the next step. Colors are used in this menu to indicate the worst condition detected by MMC in any of the setup screens.

If the operator elects to proceed, he is presented with another menu. This menu gives him the option of starting over, returning to the setup menu, proceeding with charging and firing the simulator, or generating a shot document.

If the operator elects to proceed to charging and firing the simulator, he is presented with a screen which indicates the present state of each of the major parameters. The state is indicated by colored symbols which tell whether any of the parameters have drifted out of their allowed tolerances. From this point on through the firing of the simulator, MMC uses signals generated in the simulator controls to determine what actions it should take.

During the charging of the Marx generators, the charging voltages and currents are monitored and displayed for each generator. Both supply polarities are monitored so that there are a total of eight voltages and eight currents involved. It was intended that error bars and colors would be used with the voltage displays. The error bars would be calculated from the Marx parameters and integrated charging current to indicate a range of expected charge voltages as a function of time during charging. This feature of MMC has been disabled due to the data transmission time required to continuously update the display. Similarly, it was intended that all of the switch pressures would be continuously monitored during

charging. This was abandoned for the same reason.

The time required to update the display during Marx charging could be reduced by replacing the Tektronix terminal. This would permit much more useful information to be displayed and monitored during this crucial phase of simulator operation. The cheapest approach would be to replace the terminal with a Personal Computer (PC) equipped with high resolution color graphics capability. The PC could then contain and execute the programs necessary to generate the displays and the main MMC computer would only have to transmit the actual simulator data. At the present time, the computer has to transmit all of the data associated with defining and altering the display. Plans to implement this approach were abandoned due to budgetary constraints.

Following a shot, a review screen is presented to the operator. It contains color-coded information about data collected by MMC after the shot. This data includes the switch pressures and simulator vacuums, as well as all of the data from the CAMAC system with the exception of the transient recorders. If the tolerances have been set appropriately in the database, this display can indicate whether the shot was normal or isolate the location of problems.

After the operator has reviewed this screen, MMC recovers the data from the transient recorders. The operator is then presented with a menu that allows the selection of a shot document which is described in Section 2.6.5. After the shot document screen, MMC returns to the menu from which the operator can elect to charge and fire the simulator again, return to the setup of simulator parameters, or leave MMC.

Selection of options from each of the menus is accomplished by setting the terminal's cursor over the desired option and pressing a key on the terminal's keyboard. Because of the physical structure of MMC, there are significant pauses in the transitions between some of the screens.

2.6.4 MMC Database.

Information about the MMC system and the simulator is contained in two data files termed the Configuration File and the Calibration File. These files allow a great deal of flexibility in the operation, maintenance, and future development of the MMC system. The configuration file contains all of the information concerning the nominal val-

ues of simulator parameters and their associated tolerances. It also contains some information related to the conversion of CAMAC data to actual values for data. The calibration file contains all of the information that is required to link the internal variables of MMC to physical data channels in the CAMAC hardware. It also contains the rest of the information required for calculating actual values for data.

Since all of the nominal values of simulator parameters are specified in the configuration file, changing all of the values to correspond to different shot requirements simply requires directing MMC to read another file. However, it is necessary to develop a library of files to describe each frequently used simulator configuration. Once this is done, the task of the operator in setting up the simulator will be simplified.

Placing the information required to link MMC with the CAMAC hardware in a data file rather than "hard wiring" it into the software has two advantages. A failure a single data channel within the CAMAC hardware can be circumvented by reassignment of the signal to a functioning channel, if one is available. This is accomplished by moving the signal cable to the appropriate input and changing an entry in the Calibration File. The existence of the Calibration File makes it relatively easy to add more signals to the system at a future date.

Unfortunately, the "calibration constants" that are necessary to convert CAMAC data into actual measured values are distributed between the two data files. This had to be done because of the restrictions placed on the code by the computer's architecture. It was originally intended that all of this information would be stored in the calibration file. As a result of this compromise, a portion of the calibration data must be replicated in each configuration file, and all configuration files must be altered if the calibration data is changed.

MMC contains no provision for altering the database files. Instead, these changes must be made using a standard text editor and knowledge of the computer system.

2.6.5 Shot Document.

The Shot Document is a printed record of the most important data acquired by the MMC system as a result of firing the simulator. Two forms of the document are available: the short form and the long form. It is intended that the short form be generated following a normal shot and the

long form only after an abnormal shot since it requires more time to prepare and print. MMC can prepare a Shot Document for any shot from information stored in the Archive File described in Section 2.6.6.

The shot document contains two types of information: tables and graphs. The tables list nominal values and postshot measured values for simulator parameters. The values measured after the setup phase as well as just prior to the shot are also listed when appropriate. Graphs are used to present the Marx charging voltages and currents as a function of time, as well as all of the data obtained from the transient recorders.

A laser printer was substituted for the original dot matrix printer when it was determined that the shot document would take an excessive amount of time to print. The laser printer was simply substituted for the dot matrix printer. "Bit mapped" graphical information is prepared by MMC and transmitted to the printer. The simple substitution of printers results in an acceptable time for the preparation and printing of the Shot Document. The process could be shortened further by preparing and transmitting the graphs in "vector" form. Plans to do this were abandoned due to budgetary constraints.

2.6.6 Archive File.

The Archive File is a computer readable file which contains all of the information acquired by the

MMC system as a result of charging and firing the Aurora simulator. A new file is created for each shot so that a "permanent" record of each shot is maintained. MMC can generate a long form or short form shot document from the data contained in an archive file whenever directed to do so.

2.7 SUMMARY.

This review of the MMC design includes the history which led to selection of hardware and software approaches to the project. It also contains a brief description of the system's organization and operation. More detailed information can be found in the remainder of this report and the Operation Manuals.

A number of tasks within this project were abandoned due to budgetary constraints. A substantial amount of work was performed on many of these tasks, and their completion would enhance the utility of the MMC system. In addition, realizing the full power of the MMC system to assist in the operation of the Aurora simulator is dependent upon the generation of databases which contain nominal values and tolerances for all simulator parameters including both those set prior to a shot, and those obtained as a result of a shot. This database can only be generated from operational experience with the simulator following completion of the MMC system.

SECTION 3

MMC SOFTWARE

3.1 INTRODUCTION.

The MMC system has been developed to assist in the operation of the Aurora simulator by simplifying the setup of the simulator and automating the collection and archiving of data related to its operation. It consists of both commercial and custom hardware and software.

At the heart of the MMC computer system is a Digital Equipment Corporation (DEC) PDP-11/44 minicomputer with an RSX-11M- plus operating system. A DEC RA-80 disk drive and DEC TU-10 tape drive provide file support for this computer. A Tektronix 4107A color graphics terminal is the interactive link between the simulator operator and the computer. A DEC LN03-plus laser printer produces tables and plots of data that is collected from the Aurora machine. Finally, a Kinetic Systems 2050 Serial Highway Driver connects the computer to the "real world" data. It provides hookup from the backplane of the computer (the Unibus) to the CAMAC system.

As mentioned earlier, the limitations of the BDM software package convinced PSI to develop a new, general-purpose data acquisition software package -- MMC. The software package consists of several routines exclusively developed by PSI, the only exception being a set of functions that control the Serial Highway Driver.

Although MMC contains a letter which stands for "control", the only control function implemented in MMC at this time is the rather minor task of setting the delays between the signals which trigger the Marx and Blumlein TAGs. With this exception, the system is totally passive. If the timing signals are generated by the original hardware system, the MMC system does not have to be functioning in order to operate the Aurora simulator in the same manner as was used prior to the installation of this system.

The execution of MMC is controlled by a set of "menus" from which the operator makes selections by positioning the terminal's crosshairs. You are thus guided through MMC without the necessity of memorizing commands or being intimately familiar with the structure of the program.

3.2 THE STRUCTURE OF MMC.

The software can be analyzed from two viewpoints: the logical structure and the physical structure. The logical structure is more natural; it infers to software as seen from the end-user, the Aurora control room operator. The physical structure is much more difficult; it refers to the implementation of the MMC software package on a computer with limited addressable memory, the PDP-11/44. The logical structure is described first.

3.2.1 The Logical Structure of MMC.

Operation of the Aurora simulator with the assistance of MMC consists of a sequence of steps which are:

3.2.1.1 File Reading. Since operation of the Aurora simulator involves the specification of a large number of parameters (gas pressures, voltage setpoint, etc.) manual entry of all of the required parameters prior to each shot would be a formidable and time consuming task. MMC avoids this problem by reading all of the required information from files stored in the computer. The file reading step allows you to specify which files and thus which parameters to use for a given shot.

3.2.1.2 Setup. During the setup step, the operator can alter many of the parameters values which have been read by MMC from the files. A color coding scheme is used to warn you of simulator parameters which deviate too far from the desired values.

3.2.1.3 Precharge Review. Following the setup step, MMC reviews all of the measured simulator parameters, compares them with the desired values, and shows the results of the comparison in a simple form.

3.2.1.4 Marx Charging and Simulator Firing. MMC monitors the charging of the Marx generators and compares the measured Marx charge voltage with the expected voltage calculated from the charging current and Marx parameters. The results of this comparison are continuously displayed until the simulator is fired.

3.2.1.5 Post-Shot Review. Following a shot, machine parameters are measured and

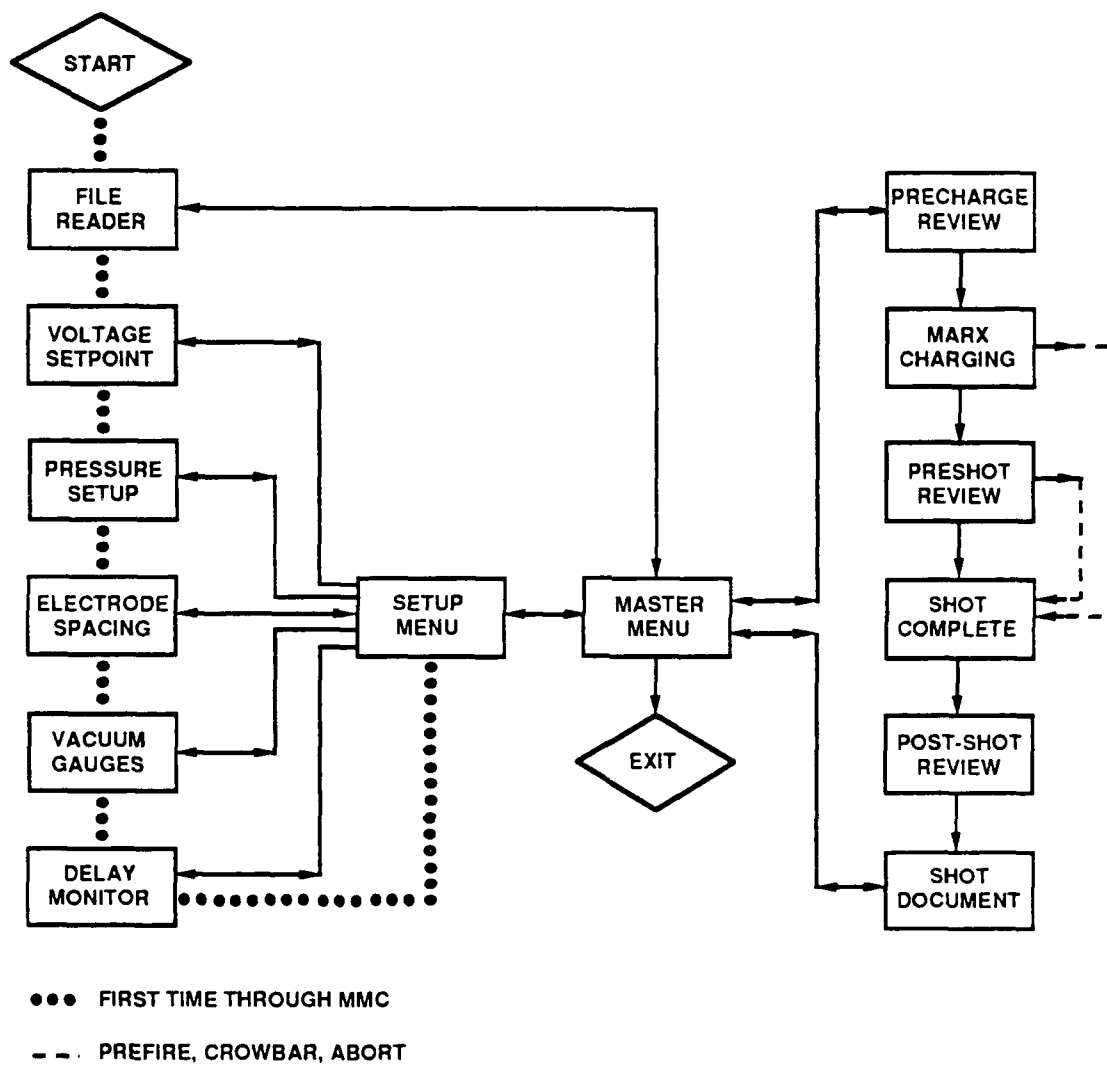


Figure 3.1. MMC flow between screens.

compared with the desired values, and data generated by the simulator is acquired and compared with expected values. The results of these computations are displayed.

3.2.1.6 Shot Document. The operator can select one of two sets of data from a shot for a printed record.

When MMC is started, the operator is required to complete the file reading step and all parts of the setup step. Once completed, neither step need be repeated unless you wish to change a parameter or a simulator parameter drifts out of compliance with the desired value. Thus after a shot has been fired, subsequent shots with the same parameters can be fired by returning to the pre-charge review step. This operations convenience adds some confusion to this manual since the flow of MMC depends upon whether MMC was just started or whether the file reading and setup steps have already been performed once (see Figure 3.1). The sections below assume that MMC has just been started, deviations from the description for subsequent passes are noted.

3.2.2 The Physical Structure of MMC.

The scope of each of the tasks is as follows:

3.2.2.1 MMC0. MMC0 contains the initial MMC banner and the configuration and calibration file readers. MMC0 is always the first task that executes upon entry to MMC, or it may be entered when CONF/CALB is selected from the master menu. Upon successful completion, MMC0 always exits into MMC1.

3.2.2.2 MMC1. MMC1 contains the master menu, the setup menu, and each of the individual setup screens: pressure setup, charge voltage setpoint, electrode spacing, vacuum and delay. Because MMC1 contains the master menu, MMC1 can invoke any of the other tasks or be invoked by them. MMC1 is also the normal way out of MMC via the EXIT rectangle in the master menu.

MMC1 actually has a single entry point, but acts as if it had two. When invoked from MMC2 or MMC3, MMC1 displays its master menu; when invoked from MMC0, MMC1 displays each of the setup screens in turn before entering the master menu.

3.2.2.3 MMC2. MMC2 monitors the Marx charging and firing and collects the data. MMC2 is entered from the master menu in MMC1 when the operator selects the Marx Charge rectangle. MMC2 contains the pre-charge review, Marx charging, preshot review, and post-shot review screens. Upon successful completion of all these screens, MMC2 exists into MMC3; but if a shot is aborted, MMC2 returns to the master menu in MMC1.

3.2.2.4 MMC3. MMC3 produces the shot document and, when entered from MMC2, increments the shot number. MMC3 may be entered directly from MMC2 or through the master menu. MMC3 always exits to the master menu.

The physical structure of the MMC software package (see Figure 3.2) will be described in two parts. The first part provides an overview to how the MMC software is currently implemented. The second part briefly reviews the evolution of the MMC software to its current state.

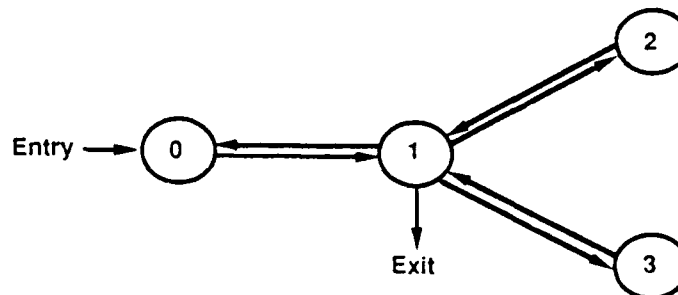


Figure 3.2. Diagram of the MMC tasks.

The MMC software is very large and complex. It is so large and complex that, in fact, the RSX-11M-plus task builder cannot handle all the MMC software at once, even the slow version designed for building large tasks. Therefore, the MMC software is divided into four separate tasks numbered MMC0, MMC1, MMC2, and MMC3. These tasks are invoked when needed under the control of the command file MMC.CMD. In spite of the overall size of the software, though, MMC does not make use of the multi-tasking capability of the RSX-11M-plus operating system; only one MMC task is running at any time.

The command file MMC.CMD acts as the glue that binds the tasks. The following paragraphs describe the control as if the separate tasks invoked each other directly. The MMC tasks only appear to work this way; they actually exit to MMC.CMD and MMC.CMD invokes the next task.

Each task can also break out of MMC altogether via the MMC error handling. Any task may abort in this way, but an exit of this sort is much more likely from MMC0 or the initial stages of MMC1 than from the other parts of MMC.

Because each task is removed completely from memory before the next task is initiated, the tasks must communicate with each other via disk files. In addition, MMC reads and logs information into other disk files.

Among the most important of the inter-task communication files is a binary sequential access file of the CAMAC data structure that each task creates just before exiting and that the next task reads and deletes. In addition, some of the more serious MMC errors generate diagnostic files that are not deleted. The diagnostic files may then be used to debug the MMC software.

3.2.3 The Evolution of the Software.

Phase I of MMC began with a careful evaluation of the BDM software package. The purpose was to identify any modules that could be incorporated into the MMC software. The only routines that proved to be valuable were associated with the control of the Serial Highway Driver. This allowed PSI to quickly access the CAMAC hardware system through the computer. Eventually, even these routines were replaced by a commercial software package developed by Kinetic Systems. The commercial package had more features and proved to be more reliable than the BDM routines.

Phase II consisted mainly of processing the "fast" signals -- readily transient recorder waveforms, peak-reading ADC's, integrating ADC's, and timing modules; putting the output for these signals into the shot document and so on. This phase of the development started after the September 1986 visit and continued until the calibration in March 1988. Phase II also included two other visits to HDL, one in October 1987, and the other in December 1987.

From the very beginning PSI realized that it would be a large undertaking to fit the MMC program into the available memory. Although the computer had three megabytes of random-access memory (RAM) and a large hard disk, the computer's architecture runs such that only 64 kilobytes of memory was available at any given time. Much of that being usurped by the FORTRAN library routines, especially the error handling and the input/output routines. Indeed the small RAM address space has proved to be a persistent problem throughout the MMC design cycle. More will be said later about the measures taken to address this problem.

The three major functions to be implemented first in MMC were to be closed-looped electrode spacing, data acquisition of the Marx charging waveforms, and gas pressure monitoring. Of these, Marx charging was started first, followed shortly thereafter by the pressure setup.

The PSI software team concentrated on these particular functions early, partly because of their importance to the HDL operators, partly because these functions could be expected to be the most troublesome and would take longer to develop. The Marx charging was also a real-time process, in which the data must be acquired "on the fly" and displayed within a fraction of a second of sampling. This requirement constrains the type and amount of software that can appear in the sampling loop.

PSI's goal for Marx charging was two samples per second, which is the period that Marx voltages can have a noticeable change during charging. Although PSI spent some time and money to meet this goal, the best that could be achieved was one sample in approximately 0.8 seconds. Nevertheless, HDL appears to consider the update speed quite satisfactory.

During the very early part of Phase I, extensive benchmark measurements of the Marx charging loop was taken to locate the reason for the slow cycle period. Measurements showed that the

loop was limited mainly by the speed with which the computer could write information to the display. Hand calculations of transmission speed agreed fairly well with this conclusion, the discrepancy being chalked up to software overhead.

The next software task pursued was the pressure setup screen, not so much because of its complexity as much as HDL's need for a reliable pressure monitoring system. HDL had instruments to control and measure gas pressures at the time, but the sensor readouts were under the Marx banks and could not be read from the control room. Furthermore, pressure instruments were not easily calibrated. The pressure sensors system that PSI installed allowed easy calibration and the ability to read the pressures in the control room.

The pressure setup screen proved to be an invaluable prototype that could be cloned fairly easily to produce the other setup screens.

The pressure setup proved to be the most tractable of the Phase I MMC functions, and apparently one of the more useful MMC features. When MMC is running, HDL usually has the pressure setup screen displayed except when actually firing a shot or using another MMC feature.

As currently implemented in MMC, the computer only monitors the electrode spacing. Software to calibrate and control the electrode switches was written but not fully tested. The closed loop control routines were not incorporated into MMC due to budget constraints of the MMC software Phase I development.

Although PSI did not specifically mention error handling in the original MMC conceptual design, it is implicit that a software package with the size of MMC has a consistent and general set of error handling subroutines. This is especially important in a complex package like MMC that requires a lot of information from the user. To this and the MMC package is heavily loaded with validity checking, especially on the data file readers. In addition to making the package easier to use, the error handling also proved useful in MMC's development. For this reason, the error handling software in MMC and most of its related utilities is fairly complex.

However, the bulk of Phase II time was spent in developing the data structures and routines to process fast signals, i.e. signals from timing modules, peak-rising ADC's, integrity ADC's and

transient recorders. Much of this work was in expanding the CAMAC data structure and routines and the shot document to read and display the new data, but other parts of MMC were affected also. The new information required new setup screens and expanded post-shot review screen. The data file reader and the archiving software was also expanded.

Since the nominal values of many quantities should be scaled with charge voltage, fields in the data structure of the MMC file reader are reserved for this purpose. The syntax of this data file is detailed in a document on the MMC computer.

While the development was proceeding, the limited 64k byte address space became an ever increasing constraint. In an effort to gain effective memory, the PSI software team incorporated specialized features of the RSX-11M-plus operating system into the MMC task building process.

At first it was possible to fit the whole program into memory but very soon it became necessary to use overlays, overlaying being a method of storing part of the program on disk in an inactive part of memory until it is needed.

About this time, the developers had taken the extra step of creating object code libraries. In object code libraries only those computer routines actually needed are linked into the computer task to be run. Otherwise all the routines in the object file get linked into the task whether they are needed or not. Leaving the unused code out of the task, of course, saves memory space.

In the early stages of MMC, it took only about five minutes to build a simple task. The task building time steadily expanded to its current length of about 30 minutes. In order to keep the system resources free during this time, namely the terminals, the task builds were submitted to a batch processor. The batch processor acts as a virtual terminal. The batch processor sends all of its I/O to the disk drive. This feature was very valuable to the developer since something else could be done from the terminal while the batch job was running. Otherwise, the terminal's usefulness would have been severely curtailed while the task build was in progress.

In an attempt to reduce active storage requirements, the PSI developers considered using virtual arrays for some of the larger data areas, but a long list of restrictions on the use of virtual arrays made this option unattractive. Virtual arrays

require a fixed eight kilobytes of memory regardless of the size and of virtual arrays. Because MMC has very few arrays even approaching this size, arrays would have to be combined to make the scheme worthwhile. This coupled with the other restrictions on virtual arrays, caused the idea to be shelved for the remainder of Phase I.

As the MMC software grew, the overlay tree became more complex and it became steadily more difficult to produce an executable task. Eventually, the task became too large for the default task builder to handle. At this point, PSI started using what is known in DEC argot as the slow task builder. The slow task builder, though slower, can build larger tasks.

However, before the breakup of MMC, two other major features were incorporated into the task -- co-trees and I (instruction) and D (data) space. Co-trees, although saved no memory directly, allowed the error handling to be broken up into overlay branches and allowed some of the more primitive graphics routines to share address space with the error handling, a feature otherwise difficult to perform.

Of all the techniques used to get the tasks to fit into the limited address range, invoking the I and D space was second only to the use of overlays in its effectiveness. With this operation, the address space is broken into instruction (I) space and data (D) space with a range of 64 kilobytes in each. This doubled the available space. Although instruction space was still tight, it allowed for an almost penalty-free increase in data space, and it also allowed more code to fill the space vacated by the data. Inside from altering the Kinetic System software package slightly to run in I and D space, this changeover occurred almost without incident.

Eventually the MMC software became too large for the slow task builder. At this point, it was necessary to break the software into smaller tasks. This was not a trivial task since it meant a major reconstruction of the MMC program. The software was transformed from one huge task into four smaller tasks. This required several things:

- (1) a way to control which task was to execute next;
- (2) a way to pass information between tasks; and
- (3) a time-out from other MMC software development.

Even though the PDP-11/44 has a limited address space, it was possible to implement the MMC software via extensions to the computer's operating system. Using these extensions required structural changes to the software that give MMC its present form.

3.3 SIGNAL NAME CONVENTIONS.

The MMC software does not make direct references to the hardware. Instead, it references signal names that are declared in the configuration and calibration files. These files make the necessary hardware to software connections. The following discussion introduces the signal naming conventions used throughout the software.

The generic signal name is divided into three distinct parts: the signal type designator (first character), the hardware type (second and third characters), and the signal character designator (fourth character). The fifth character appended to a generic signal name to convert it into a specific signal name is called the channel designator (see Figure 3.3).

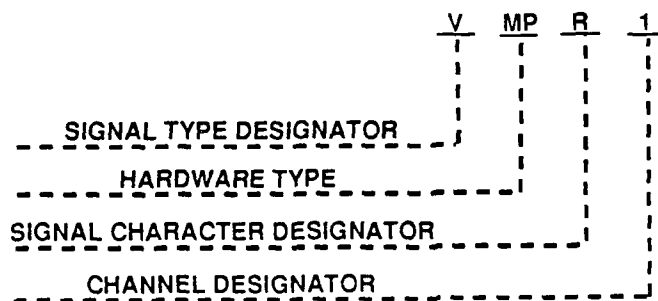


Figure 3.3. Parts of a signal name.

Even though the signal character is fourth in the string, it will be described first because the interpretation of the signal type designator (i.e. the first character) depends upon whether the signal is analog or digital. The signal character designator specifies whether the signal is digital or analog, whether the signal is an input to or an output from a CAMAC unit, or even whether the signal is associated with a CAMAC unit at all. Most CAMAC units can send or receive on their data channels only a very limited number of different signal characters.

Signal characters A, S, C, and R are collectively called analog single-value designators. All four denote analog inputs into CAMAC units that the computer reads as a single value. characters R and C signals typically feed into analog-to-digital converter (ADC) modules such as the LeCroy 8252 and the LeCroy 8212A. Character A signals represent peak amplitude of waveforms as read from a 2259B Peak-Sensing ADC. Character S signals represent summations (integrals) of waveforms as read from a 2249SG.

The difference between a control signal (character C) and an analog reading signal (character R) is mainly where the signal originates: an analog reading signal is considered to originate directly from the Aurora pulser and represents a status, whereas a control signal may originate from the Aurora control circuitry or another CAMAC unit. At present, the only control signals are TCOC 1 and 2 from the PSI-fabricated clock module. These signals are considered to control the charging clock signal, TCOR1. All the other analog signals in Phase I that feed into the CAMAC units are analog readings and have the fourth character R.

Signal characters G, L, and T are timing signals. Timing signals feed into the gates and data channels of timing-to-digital converter (TDC modules) and into the gates of transient recorders. Signal characters L and T correspond to leading and trailing edges, respectively, of pulse-shaped waveforms coming more-or-less directly from the Aurora pulser, whereas the gate signals (character G) tend to be the result of AND or OR operations and are intended primarily to be gating signals for the CAMAC modules. However, any

timing signal can serve as a gate, and character G signals have values just like other timing signals: the difference between G, L, and T signals is conceptual only.

All gating and timing signals must feed into at least one TDC gate or data channel to be measured, except the signal TTOG1. TTOG1 is a special signal that the MMC software implicitly declares and is the standard timing mark against which all other timing signals are measured. TTOG1 is the only signal that is not explicitly declared in the configuration file.

Character H signals are waveforms read from transient recorders. As such, character H signals differ from other signals so far discussed in that they consist of a group of numbers defining a waveform instead of just one number. Although superficially similar to the Marx charging histories, character H signals differ in the kind of CAMAC modules reading them and in the fact that the sample intervals are equally spaced in time. On the other hand, the 8212A module reading the Marx charging waveforms, although capable of being used as a slow transient recorder, is treated instead as a triggered ADC in the MMC software. The MMC software also reads timing information with each Marx charging sample and the intervals between samples are not necessarily equal.

Fourth character W denotes an analog write signal unless the first character is T, in which case it is a timing write signal. These two signal characters are separate and distinct and have dissimilar properties; but they share the feature that the signal flow is from the computer to the analog or timing output of the CAMAC module.

Analog write signals are associated with digital-to-analog converters (DAC's) as opposed to ADC's where the signal path is in the opposite direction. At present, the only CAMAC module that processes analog write signals is the 1024 Trigger Module, where the DAC function is not obvious. Nevertheless, it is there in the form of a discriminator setpoint. Timing write signals are associated with the 2323 Gate and Delay Generator, which can be thought of as a reverse Time-to-Digital converter (TDC) in a way analogous to the way a DAC is an ADC in reverse.

SECTION 4

FAST SIGNAL SUBSYSTEM

The "fast signal" portion of the Machine Monitor and Control system makes quantitative measurements on thirty-one (31) signals of less than 5 μ s duration which are generated by the Aurora simulator. For example, these signals include pulse charge signals from each of the Blumleins, the voltage and current measured at each tube, and others. These signals are analyzed by two classes of CAMAC hardware and converted into digital data which can be read and processed by the MMC software subsystem. The first class of CAMAC hardware units generates a single number which describes the signal input to the unit, such as its arrival time or its peak amplitude. These units are relatively inexpensive and, because of the small amount of data which they generate, their data can be read and processed quickly by MMC. The second class of CAMAC hardware is composed of transient recorders which generate a complete digital description of the temporal behavior of the input signals. These units are relatively expensive and require more processing time because of the large amount of data that they generate.

Nearly all of the hardware associated with the fast signal subsystem is housed in a single Radio Frequency Interference-tight (RFI) cabinet. The two exceptions are the "Tapoff Chassis" which samples each of the 31 input signals for the MMC system and the transient recorder intended for use with the radiation photodiode. The architecture of the fast signal subsystem is described in Section 4.1.

All of the fast signal CAMAC units require electrical trigger or gating pulses which must be synchronized with the signals being processed. The generation of these pulses and their timing is responsible for much of the complexity of the fast signal subsystem. Due to the synchronization requirement, the fast signal subsystem must either have access to the signals which control the simulator or must generate them. The subsystem generates up to four trigger pulses required by the simulator: two for the single pulse operating mode and four for the multipulse mode. The timing of these signals is controlled by two dual channel CAMAC delay generators. The generation of these four signals is described in Section 4.2.

Each of the thirty-one simulator signals must be sampled by the fast signal subsystem, split into multiple signals, and conditioned. Each of the CAMAC hardware units has specific input signal requirements (amplitude and polarity) which must be satisfied by the signal conditioning hardware. In addition, the inputs to the CAMAC units must be protected from anomalous, high amplitude transients which could damage them. The sampling of the simulator signals is performed in the Tapoff Chassis mentioned above. All of the signal conditioning and splitting is performed by circuitry located in an RFI enclosure inside the RFI cabinet which houses the CAMAC hardware for the fast signal subsystem. These portions of the fast signal subsystem are described in Section 4.3.

The generation of the trigger and gating pulses required by the CAMAC units is described in Section 4.4. This section also describes the hardware treatment of Marx generator prefires. Timing measurements are discussed in Section 4.5.

Because of the cost of the transient records, the fast signal subsystem multiplexes more than one input signal into eight (8) of the thirteen (13) transient recorders included in the subsystem. A total of twenty-one (21) of the simulator signals are recorded. The multiplexing hardware is described in Section 4.6.

The installation of the subsystem and its calibration are described in Sections 4.7. and 4.8.

4.1 SUBSYSTEM ARCHITECTURE.

4.1.1 Component Description.

There are four types of data acquisition modules in the fast signal subsystem. These are the Long interval Time to Digital Converters (LTDCs), the Short interval Time to Digital Converters (STDCs), the Transient Recorders (TRs), the Integrating Analog to Digital Converters (IADCs), and the Peak reading Analog to Digital Converters (PADCs). The LTDCs measure the arrival times of signals over an interval of approximately 16 ms with 1 ns resolution, and are relatively expensive modules. The STDCs measure the arrival time of signals over an interval of $\sim 1 \mu$ s with 0.5 ns resolution, and are much less expensive. The TRs record a complete temporal history of the input

signals. Two types of TRs are used in the subsystem. The TRs used to record the pulse charge waveforms sample every 31.25 ns over an interval of 250 μ s, and the remaining TRs sample every 5 ns over an interval of 320 μ s. The IADCs integrate the input signals over a time interval determined by gate pulses which are synchronized to each signal. The PADCs measure the maximum signal amplitude which occurs during the interval for which they are gated. Only one gate pulse is required for each PADC.

The fast signal subsystem contains two sections which provide the signals required by the CAMAC data acquisition modules; the analog signal section which provides the properly conditioned signals to be measured, and the timing section which provides all of the required gate and "trigger" pulses. Figure 4.1 shows the architecture of the subsystem in block diagram form. The vertical array of blocks in the center of this figure are the data acquisition modules. To the left of the data acquisition modules are the components of the analog signal section of the subsystem; to the right are the timing components.

The analog signal section consists of a tap-off chassis, a signal conditioning system, an analog multiplexing system, and the discriminator modules. The tap-off chassis samples the signals from the simulator and sends the sampled signals to the fast signal subsystem, as well as making them available for use in the control room. The signal conditioning system, attenuates, inverts, splits, and again attenuates and inverts the sampled signals as needed, providing signals to the data acquisition modules that have the appropriate polarity and amplitude. The signal conditioning system also provides protection for the CAMAC module inputs. The analog multiplexing system is used to reduce the number of transient recorders in the subsystem by temporally multiplexing two signals for most of the TRs. The discriminators are used to sharpen the pulse charge signals for input to the TDCs.

The timing signal section consists of an interface module, two dual gate/delay generator modules, trigger generator modules, and gate generator modules. In addition, the discriminators become a part of the timing section in the event of a simulator prefire which results in the charging of one or more of the Blumleins. The interface module converts the timing signal generated by the simulator (TOIN) into the correct amplitude and polarity

required by the fast signal subsystem, and converts the timing signals generated by the subsystem into the amplitudes and polarities required by the simulator. A portion of one of the gate generator modules is used to synchronize the simulator timing signals to the timing section. The two delay generators determine the delays between the simulator timing signals. The trigger generator modules generate pulses for the inputs of the gate generator modules and generate "trigger" and gate pulses for some of the data acquisition modules. The gate generator modules produce nearly all of the gate pulses and the remaining "trigger" pulses required by the data acquisition modules.

If a simulator prefire results in charging one or more of the Blumleins to more than one half of the expected voltage, one or more of the discriminator modules will detect the prefire and send a signal to the trigger generator modules. This results in the generation of the timing signals required to service the appropriate portion of the timing section.

4.1.2 Equipment Layout.

It was originally intended that all of the fast signal subsystem except for the tap-off chassis would be contained in a single RFI cabinet which would house four CAMAC crates. When multiplexing of the transient recorder signals was limited to two per recorder, it was not possible to house all of the CAMAC modules in four crates. As a result, a second exception was made to locate the transient recorder which was intended to service the radiation photodiode in the crate used by the slow signal subsystem. Since the photodiode signals can also be serviced by other CAMAC modules, the signal conditioning for the photodiode was included with the rest of the signals. This requires that two coaxial cables carrying the photodiode signal and the STOP pulse for the photodiode transient recorder run between the two RFI cabinets that house the fast and slow signal subsystems. As of this time, a photodiode signal is not available for analysis in the control room.

The fast signal subsystem does not contain any signals which are explicitly referenced to the Marx generators (pulse charge signals are associated with the Blumleins). Thus it is convenient to associate one CAMAC crate with each Blumlein. The trigger amplifier gaps and trigger Marx generators can be associated with a Blumlein pair.

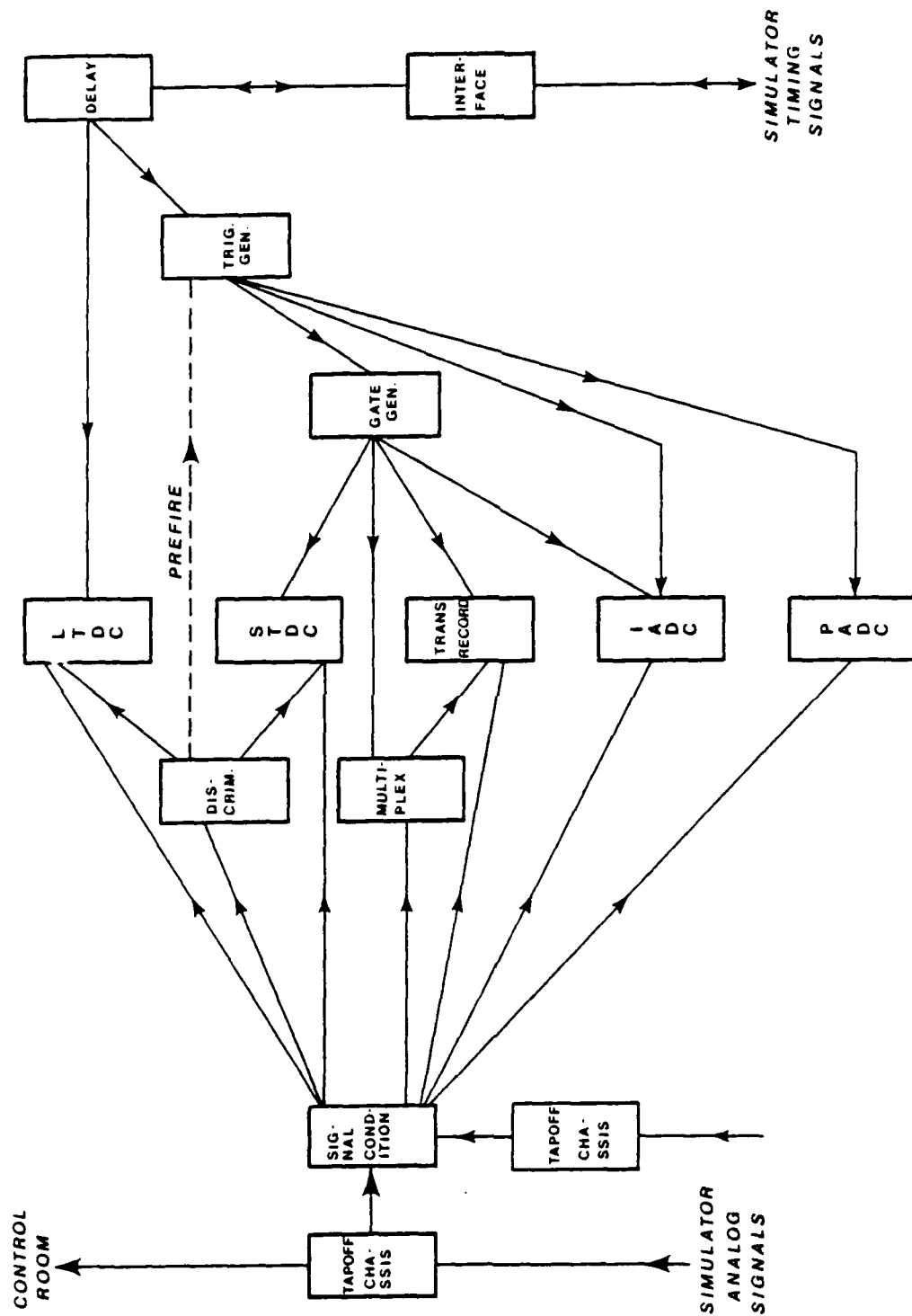


Figure 4.1. Block diagram of fast signal subsystem.

One approach to the subsystem architecture would be to populate each crate with identical hardware. This would greatly simplify the design and implementation of the subsystem. However, this approach was rejected because it would not utilize the CAMAC hardware efficiently and thus would be expensive. Furthermore, it was determined that a complete complement of CAMAC modules would not fit into a single crate so that this approach would have required eight crates for the fast signal subsystem.

Since the multipulse mode involves only the operation of Blumlein pairs (A-B and C-D), it is reasonable to service some signals for a Blumlein pair in a single CAMAC module located in one crate in order to reduce costs and fit within a four crate system. An early design of the subsystem consisted of two "master" crates which would contain a complete complement of modules, and two "slave" crates which would contain only a subset of those modules. Thus, one master crate would service all of the signals for Blumlein A and some of the signals for Blumlein B. A slave crate would service the remaining signals for Blumlein B. During the detailed design of the subsystem it was determined that one crate could not house a complete complement of modules. Rather than add two more crates, the "master-slave" architecture was abandoned although the terminology persists in some of the documentation.

The final architecture selected for the four crates of the fast signal subsystem (except for the photodiode) assigns two crates to Blumleins A and B, and two crates to Blumleins C and D. Except for the common gate generator clock, signals associated with T0, T2, T3, and T4 (there is only one "simulator interface" module as described in Section 4.2), and cable numbers, each pair of CAMAC crates is identical.

Each crate contains an IADC, a PADC, a STDC, and three transient recorders, as well as gate generator modules and a trigger generator module. The signals serviced by these modules in one crate all emanate from a single Blumlein. Thus, one crate is strongly associated with a single Blumlein. The remaining modules include a LTDC, a computer controlled discriminator, an analog switch for multiplexing, and the dual delay generators that control T0, T2, T3, and T4 as described in Section 4.2. These modules are associated with a Blumlein pair and are randomly distributed between the associated pair of crates.

The remaining module is the simulator interface which is located in crate 2 (associated with Blumlein A). The complete complement of modules nearly fills the four crates. With one slot in each crate reserved for a "dataway display" used in hardware troubleshooting, there are only a total of three empty stations in the entire fast signal subsystem. Crate 2 is completely filled except for the reserved slot.

4.2 SIMULATOR INTERFACE.

As mentioned above, all of the fast signal CAMAC units require electrical trigger or gating pulses which must be synchronized with the signals being processed. Because of this requirement, the fast signal subsystem must either have access to the signals which control the simulator or must generate them. The second of these approaches has been selected with a view to expanding the control functions of MMC at some future date. As delivered, the subsystem generates up to four trigger pulses required by the simulator; two for the single pulse operating mode and four for the multipulse mode. These signals are nominally termed t0, t2, t3, and t4.

Synchronization of the fast signal subsystem and simulator is accomplished by routing the existing T0 signal to the "T0IN" connector of the MMC system located on the rear of the RFI cabinet that houses the fast signal subsystem. The "T0OUT", "T2OUT", "T3OUT", and "T4OUT" connectors then supply the appropriate signals required to operate the simulator. These signals have the proper amplitudes and polarities to drive the trigger amplifiers of the existing system directly without the need for additional delay generators or pulse amplifiers.

The architecture of this portion of the fast signal subsystem is shown in Figure 4.2 which also indicates the locations of the relevant CAMAC modules. The T0 signal input from the original control hardware is converted in the "interface" module (PSI) to a signal that can be used by the other CAMAC modules in the system. This signal is then routed to a "gate generator" module (Jordan) where it is synchronized to the 100 MHz clock used by these modules. This introduces a random delay in T0 by up to 10 ns. The clock synchronized signal (t0s) is then routed to the "Start" input of "Channel A" of a dual delay generator (LeCroy 2323). The output of Channel A is routed back to the "interface" module where it is converted to a signal which the simulator can use, and is available at the "T0OUT" connector.

Channel B of the same gate generator determines the delay between T0OUT and T2OUT. The output of Channel B is routed to the "interface" module where it is converted appropriately before routing to the T2OUT connector.

The "t0s" signal is also routed to the "Start" input of Channel A of the second dual delay generator. The delay set for Channel A of this module determines the delay between T0OUT and T3OUT, and the delay set for Channel B determines the delay between T3OUT and T4OUT.

4.3 ANALOG SIGNALS.

Optimal use of the CAMAC modules in the fast signal subsystem requires that voltage inputs fall within a fairly narrow range. For many of the modules, the lower bound for signal amplitude is set so that the finite, digital resolution of the module is adequate for a meaningful measurement. For the time to digital converters (TDCs), the input signal must exceed a threshold amplitude for the modules to function at all. The upper bound for signal amplitude is set by the full scale range of the modules. Satisfying these requirements is complicated by the variation in signal amplitude that results from operation of the simulator at different Marx charge voltages.

One approach to satisfying the amplitude requirements of the modules would be to provide amplifiers with computer controlled gain for each of the simulator signals. This is an expensive approach and would not fit within the available crate space of the subsystem. Thus it was rejected.

A simpler approach is to use a passive tapoff and signal conditioning scheme that results in acceptable signal amplitudes with as much identical hardware as possible. The wide dynamic range of the simulator signals (from a few volts to 2 kV) makes this approach difficult, but an acceptable solution has been found that will work with signals of either polarity from 4 V to 2 kV. Only one simulator signal lies outside of this range and must be treated as a special case as described below.

4.3.1 Signal Tap-offs.

Resistive splitters were selected for the signal tap-offs due to the large amplitude of most of the simulator signals. This approach requires that all of the tap-off chassis outputs be terminated. The fast signal subsystem is protected from the excessive signal amplitude which will result from un-

terminated lines, but the subsystem will not operate properly.

The amplitude of the signals delivered to the signal conditioning system is limited to 130 V so that high density coaxial connectors can be employed for all demountable connections outside of the tap-off chassis. This imposes conflicting requirements on the tap-offs since they must attenuate all simulator signals which exceed 130 V, but cannot produce tap-off voltages less than 2 V if the CAMAC modules are to operate properly. This dynamic range is considerably less than that produced by the simulator. For this reason, two splitting ratios are employed in the tap-off chassis. Of the fifty (50) signal lines in the chassis, forty (40) employ 25:1 tap-off ratios for those signals in the range 130 V to 2 kV, and ten (10) employ 2:1 tap-off ratios to be used with signals of less than 130 V. The remaining attenuation required before the signals can be input to the CAMAC modules is provided in the signal conditioning enclosure.

The 25:1 tap-offs are a PSI design employing stripline construction and carbon composition resistors which have a low voltage coefficient and high peak power capability (see Figure 4.3). The signal transmitted to the front panel of the tap-off chassis for use in the control room has a risetime of less than 500 ps and an attenuation ratio of 1.08:1. The tap-off circuits are housed in individual metal boxes which are reasonably RFI-tight although they are not gasketed. The 2:1 tap-offs are commercial units which attenuate the signals transmitted to the front panel of the chassis by 2:1.

4.3.2 Signal Conditioning.

The signal conditioning circuits are housed in an RFI enclosure within the RFI cabinet which houses the fast signal subsystem. This RFI enclosure is mounted in the rear of the cabinet on slides so that it can be pulled through the rear door of the cabinet to permit limited access to the rear of the CAMAC crates and the signal cabling. RFI integrity is maintained from the back panel of the cabinet to the enclosure by a small RFI box and metal sheathed flexible conduits. Thus only low level signals (less than 2 V) and AC power are routed within the cabinet itself. Each input signal is routed to a printed circuit card which contains circuitry for attenuation, inversion, amplitude limiting, splitting, and further inversion and attenuation of the split signals.

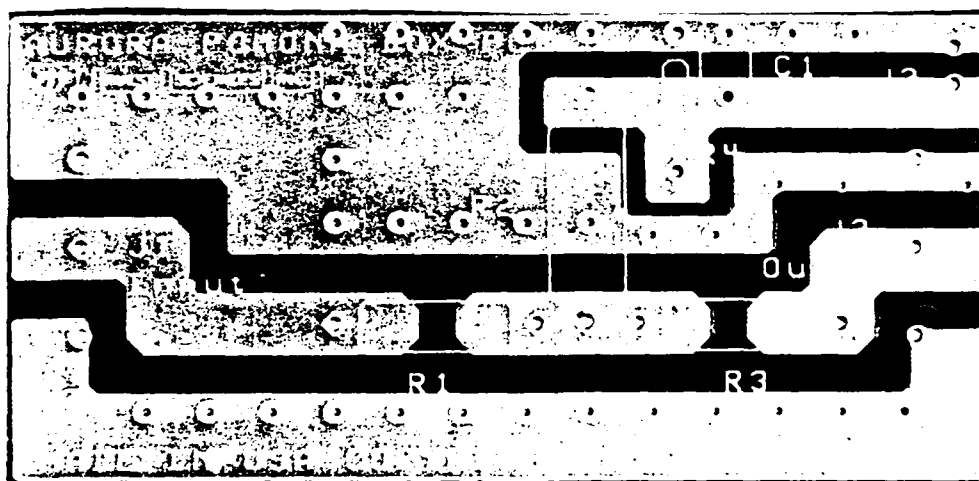
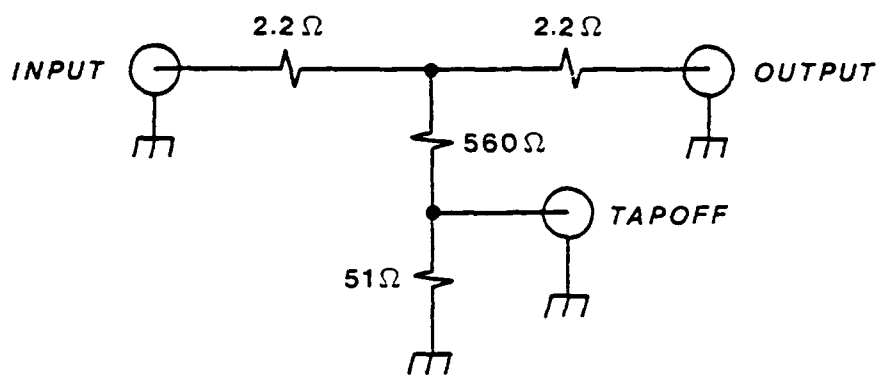


Figure 4.3. 25:1 signal tapoff.

The circuit diagram for the signal conditioning cards is shown in Figure 4.4. Space is provided for a resistive preattenuator for signals whose amplitudes exceed 65 V. This condition exists only for simulator signals that exceed 1.9 kV at the input to the tap-off chassis. The main input attenuator follows the preattenuator and provides switch selectable attenuations from 0 to 22.5 dB in 1.5 dB steps. The attenuation is selected to yield approximately 4.8 V at the output of the attenuator. The main input attenuator is followed by a pulse transformer whose windings can be selected with straps to provide inversion if necessary to produce a negative output. Thus, inversion is used only with positive polarity simulator signals. A 5 V zener diode at this point provides protection for the inputs to the CAMAC modules. A four-way resistive splitter is used to provide outputs for an IADC, a PADC, a TDC, and a transient recorder. Straps are provided for terminating unused outputs so that the splitter retains a 50 Ω input impedance and keeps the voltage at the splitting point below the threshold of the zener diode. The splitters are not designed to provide a 50 Ω termination as viewed from their outputs since this would require a larger voltage at the splitting point and complicate the design of the system.

The four-way splitter provides a negative fixed output of approximately -2 V to the peak reading ADCs at maximum simulator output. A transformer is provided on some of the cards to invert the output for use with the LeCroy 4208 TDC. The LeCroy 2228 TDCs require negative inputs and thus do not require inversion. The amplitude of the TDC output is approximately 1.35 V at maximum simulator output. Since the threshold of the TDCs is set at 0.45 V, timings will be measured at 1/3 peak at maximum simulator output. The TDCs will trigger at 2/3 peak if the simulator is operated at 1/2 of maximum. The transient recorder output amplitude is approximately -1.35 V for those signals which are fed to the delay leg of the analog multiplexing system. Switch selectable attenuators are provided for signals that are fed directly into a transient recorder. The remaining output for the integrating ADCs possesses a switch selectable attenuator which together with the strap selectable termination provides a dynamic range of nearly 30 dB. This attenuator is set so that the integrated volt-second product of the signal is consistent with the full scale 12.8 nV-sec range of the LeCroy 2249 ADCs including an allowance for the maximum expected IADC pedestal.

The splitting ratios and associated component values are the same on all but one of the signal conditioning boards. The simulator signal on one channel (TAG1) is not sufficient to trigger its TDC with the standard splitting components, so its associated signal conditioning board has a special set of resistors which provide only three outputs of the correct amplitude. The transient recorder output is missing on this board (it would not have been used anyway).

The printed circuit board for the signal conditioning circuitry is laminated so that the thickness of the board between the traces and the underlying ground plane is 0.032 inches even though the finish board thickness is 0.065 inches. The overall thickness provides mechanical stiffness while the thinner separation between the traces and the ground plane permits the use of stripline signal paths with an impedance of 50 Ω . Edge connectors employing coaxial mating manufactured by Amp are used on the signal conditioning boards.

The individual signal conditioning boards are plugged into "mother boards" which are mounted on the rear of the RFI enclosure (as viewed from its door) and near the BNC output connectors which penetrate the wall of the RFI enclosure. Seven signal conditioning cards can be plugged into each of eight mother boards for a total of 56 channels. All channels have a full complement of connectors.

4.4 TRIGGER AND GATING PULSES.

CAMAC modules that generate data require at least one trigger or gating pulse that is synchronized to the signal being analyzed. Approximately 100 such pulses are generated and used in the fast signal subsystem.

The complexity of the task of generating these pulses is increased by the CAMAC modules' demand for three different types of signals. These are designated TTL (Transistor-Transistor Logic), NIM (Nuclear Instrument Measurement standard), and double-NIM. The TTL signal must drive a 50 Ω load to the required $> +1.4$ V level. The NIM signal is defined in terms of current but is equivalent to -0.6 V into 50 Ω . The double-NIM is twice the amplitude of the NIM signal. Although some of the CAMAC modules accept, generate, and internally use ECL (Emitter Coupled Logic) signals, these do not have to be generated in the fast signal subsystem.

The generation of these trigger and gating pulses involves three types of CAMAC modules other

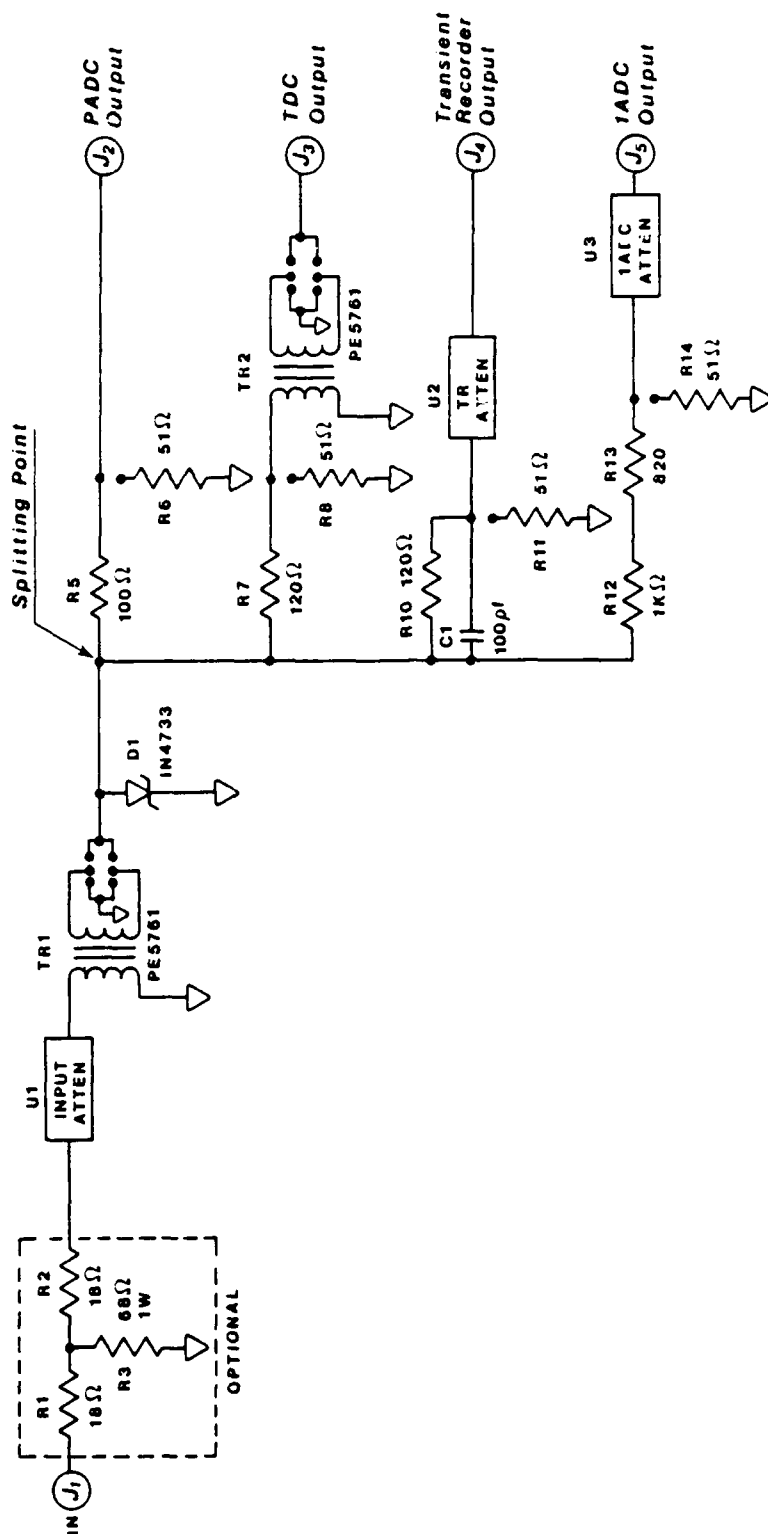


Figure 4.4. Circuit diagram for signal conditioning.

than the dual delay generators discussed in Section 4.2. above. These modules are discriminators (DSP 1024), trigger generators (PSI), and gate generators (Jordan). In an ideal world, each module would generate the correct type of signal to drive the units to which it is connected. In the real world of the fast signal subsystem, this is true for only about 90% of the signals. Four signals were TTL when NIM was required, and four needed to be both TTL and NIM simultaneously. These special cases were treated by eight, custom, passive circuits housed in small metal boxes which plug directly into the CAMAC modules.

4.4.1 Modules.

4.4.1.1 Discriminators. The discriminator modules accept pulse charge voltage waveforms and produce signals which are used by trigger generator modules and for timing measurements. The pulse charge signals have risetimes of approximately 2 μ s which are too long for reliable timing measurements if they are used as inputs to the TDCs directly. In addition, the pulse charge waveform amplitudes depend strongly on the Marx charge voltage which is a variable parameter in simulator operation. As a result, a fixed threshold reference voltage would result in substantially different timing measurements for the different pulse charge amplitudes. The discriminator modules have a computer-controlled threshold which is set by MMC to a value that is proportional to the appropriate Marx charge voltage. In addition, the discriminator modules have the capability of detecting both the leading edge (Blumlein charging) and trailing edge (pulse switchout) of the pulse charge waveforms whose timings can be measured with the TDCs.

The discriminator modules perform an additional function in the event of a Marx prefire. The LTDCs make measurements on signals from both halves of a Blumlein pair (e.g. A-B). Thus, these modules must receive a start pulse in the event that either of the associated Marx generators prefires. This requirement is satisfied by programming the discriminator modules to produce an OR output on the first pulse charge leading edge that is detected and using this signal to trigger the respective LTDC. Since the start time for the LTDC is not known absolutely, a signal related to T0 is fed into another input of each of the LTDCs so that MMC can calculate the time of all events relative to T0. This approach

means that the LTDCs are dependent on the integrity of the pulse charge signal chains. However, both chains in a Blumlein pair would have to fail to disable one LTDC, and the rest of the MMC system would not be affected.

4.4.1.2 Trigger Generators. The trigger generator modules produce some of the trigger and gate pulses required by the signal acquisition modules as well as the trigger pulses required to drive the gate generators. Each of the four trigger generator modules has two independent input channels and ten output drivers which can be activated by either of the input channels.

Outputs from the trigger generator modules are used directly for the STOP pulses used by the transient recorders. Other outputs are used with inverters as gate pulses for the PADCs which will acquire signals only when gated. These pulses are sufficiently long to overlap all of the simulator signals and thus satisfy the requirements for the gating pulses. The remaining trigger generator module outputs drive inputs for the gate generator modules.

Each input channel accepts both a primary and a secondary trigger input. Under normal conditions, the primary trigger will arrive first and will activate the selected output drivers. If the secondary trigger arrives before the primary trigger, the output drivers are still activated, but in addition, a Secondary First (SF) pulse is generated which can be detected by a peak reading ADC so that MMC is aware of which trigger source has activated the trigger/gate circuitry.

The primary/secondary trigger logic of the trigger generator modules permits the system to acquire data in the event of a Marx generator prefire. Under normal conditions, the primary trigger inputs will control the timing. These inputs are driven by signals related to T0 and T2 (T3 and T4 if appropriate). The secondary trigger inputs are driven by outputs from the discriminator modules that are related to the appropriate pulse charge signal. It would be possible to use only the pulse charge signals for generating the timing signals for events which occur after the leading edge is detected. However, this complicates the system further and would make data acquisition dependent completely on the integrity of the respective pulse charge monitor and signal conditioning chain. Any problem

in one of these chains would then disable one-fourth of the MMC system until repairs were made.

4.4.1.3 Gate Generators. The principal function of the gate generator modules is to produce the double-NIM gate pulses that are required by each input channel of the IADCs. However, these modules are also used to generate other trigger and gate pulses. These modules were developed and manufactured by Jordan Technology for PSI. Each module contains three pairs of output channels which can be programmed independently with delays and gate pulse durations up to 2.55 μ s in 10 ns steps. Programming is accomplished with switches accessible from the sides of the modules when they are removed from the crates.

The delays and gate pulse durations are generated with binary counting circuitry which is driven by a 100 MHz clock. In order to ensure that all of the timing intervals are synchronized to each other and to the simulator, two steps are necessary. First, the modules are set up to be driven by a common clock located in one of the gate generator modules. This ensures that the gate generator modules are synchronized with each other. Second, T0 must be synchronized to this same clock. This is accomplished, as described in Section 4.2, by sending the externally generated T0 signal into the master gate generator module which then produces an output pulse on the next clock pulse. This introduces a random delay in the T0OUT signal of 0 - 10 ns which is not expected to adversely affect simulator operations. In applications where this uncertainty might be important, the master gate generator module can be bypassed making the MMC system timing uncertain to 0 - 10 ns instead.

4.4.2 Timing Signals.

The architecture of the timing signals is shown in the block diagram of Figure 4.5. The T0 signal input from the simulator system is synchronized to the MMC system clock and used to start the dual gate/delay generators which generate t0, t2, t3, and t4. These are returned to the simulator. The t0, t2, t3, and t4 signals are used as primary trigger inputs to the trigger generator modules. The secondary trigger inputs to the trigger generator modules are driven by the leading edge of

the pulse charge signals in order to provide timing signals in the event of a Marx prefire. Some of the outputs of the trigger generator modules are used to trigger and gate data acquisition hardware directly. The remainder are used to trigger the inputs to the gate generator modules which, in turn, provide the remainder of the trigger and gate signals required by the fast signal subsystem.

4.4.2.1 Normal Simulator Firing. With normal firings of the simulator, the timing subsystem can be visualized as a tree structure with T0IN as the trunk. If branches are created only when it is possible to introduce variable timings, then branches can only be created by the LeCroy 2323 dual gate/delay generators and by the Jordan gate generators. The resulting tree structure for a normal shot is shown in Figure 4.6. Four main branches are created by the LeCroy 2323 dual delay generators (t0, t2, t3, t4). Each of these main branches has numerous minor branches which are created by the Jordan gate generators. The trigger generators are included in Figure 4.6 only to indicate where secondary signals are injected in the event of a prefire.

The timing system is complicated by the fact that most of the signals are associated both with a timing pulse (t0,t2,t3,t4) and with a Blumlein PFL (A,B,C,D). However, some signals (TAGs and Trigger Marxes) are associated with a timing pulse and a pair of Blumlein PFLs, and one signal (photodiode) is associated with up to two timing signals (t2,t4) and all of the Blumleins. On a normal shot in the single pulse mode, these cross-relationships pose no problems. In this case, all of the timing signals fall into two classes: those associated with t0, and those associated with t2. On a normal shot in the multipulse mode, there are five classes of signals: those associated with t0, t2, t3, and t4, and the photodiode. The fast signal subsystem considers that the simulator is always operating in the multipulse mode and provides for four classes of signals (those associated with t0, t2, t3, and t4). The single pulse mode is simply a special case for which t0 = t3 and t2 = t4. If the delay generators which control the relative timing of t0 and t2 are altered manually when the simulator is being operated in the single pulse mode, then the operator must set the time delays so that t0=t3 and t2=t4. In the event of a prefire, the situation is much more complicated and is described below.

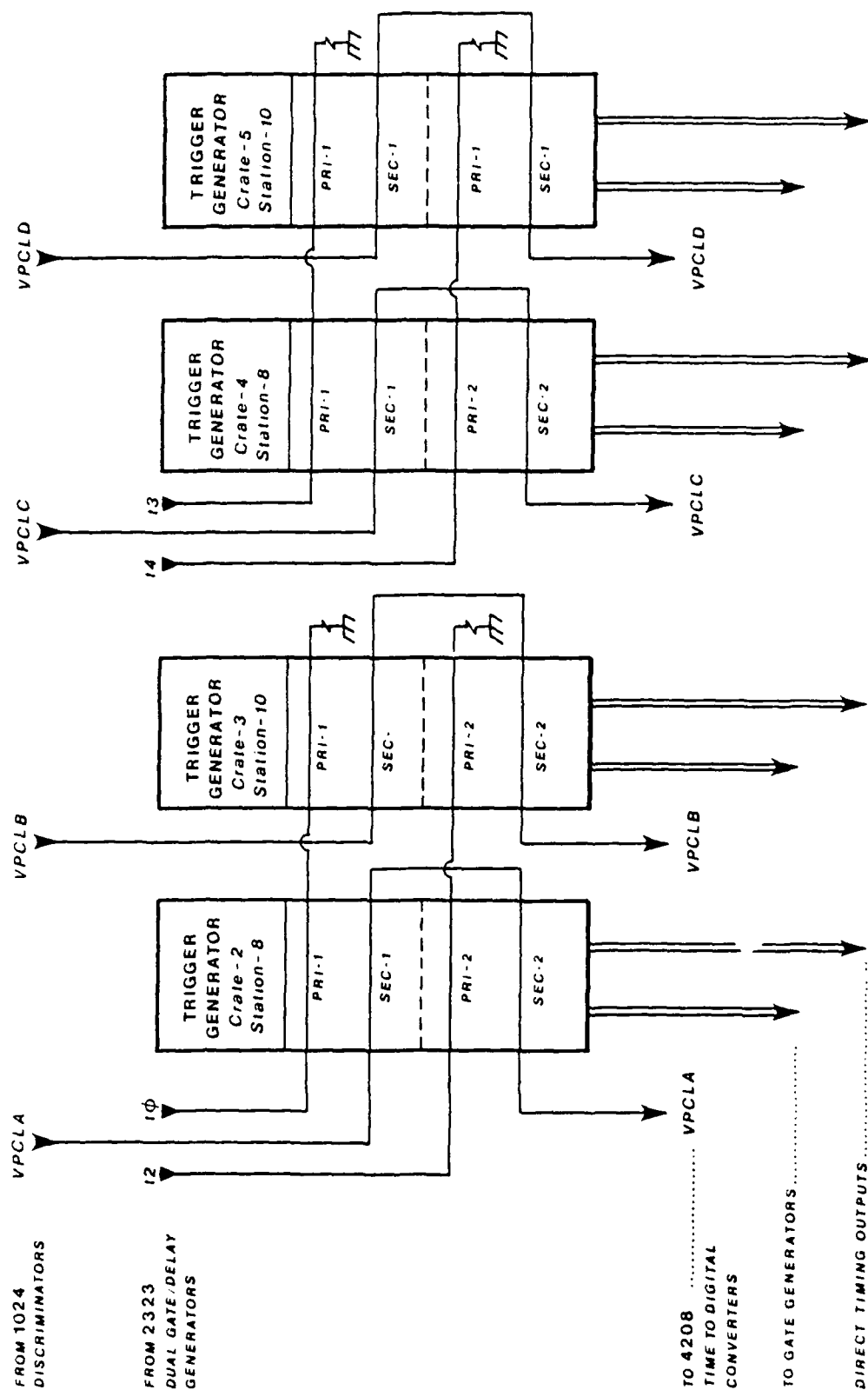


Figure 4.5. Architecture of trigger generator module signals.

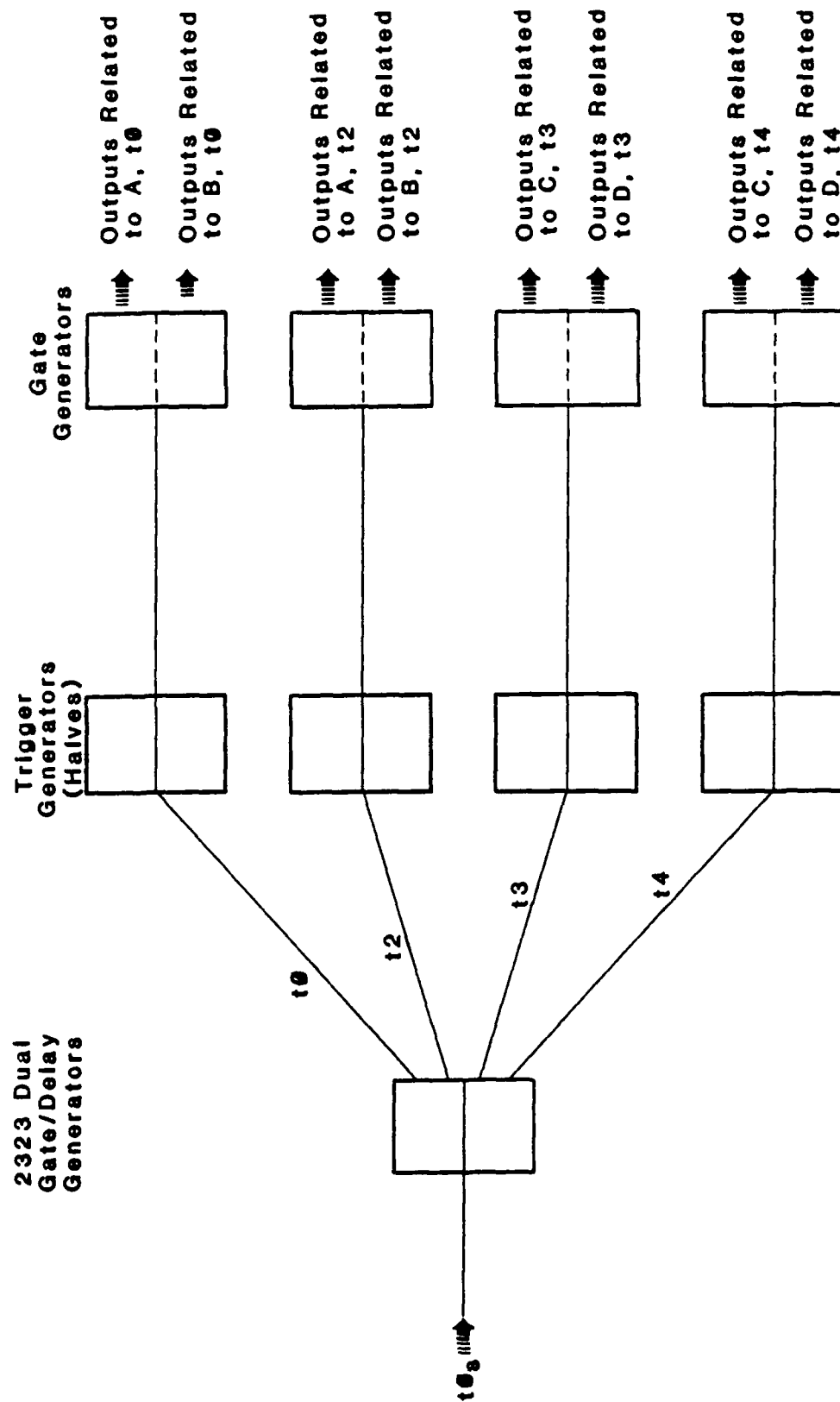


Figure 4.6. Timing tree for normal firing of simulator.

The branches of the tree associated with t0 and t3 ultimately provide trigger signals for TAG1 and TAG3 which in turn drive the trigger Marx generators. Thus these two branches generate timing signals which are related to these devices as well as the pulse charge signals generated by the main Marx generators. The t2 and t4 signals ultimately provide trigger signals for TAG2 and TAG4 which lead to the breakdown of the Blumlein oil switches and thus produce the Blumlein output pulses. The two branches of the timing tree that are associated with t2 and t4 thus contain the timing signals that are related to the oil switches and Blumlein outputs.

The outputs of the gate generators can be separated into groups associated with each of the Blumleins. This leads to a total of eight groups of timing pulses shown in Figure 4.7. This separation is not necessary for normal firings of the simulator, but is essential to the discussion of timings in the event of a Marx prefire.

The photodiode responds to radiation output from all four of the electron beam diodes driven by the Blumleins of the simulator. In the single pulse mode of operation and normal firing, this poses no special problem. The timing of the photodiode can be taken with respect to either t2 or t4 since $t2 = t4$, and the signals can be processed in any crate since the timings are the same in each crate.

In the multipulse mode and with a normal shot, the photodiode poses a unique problem in that it generates data at two widely spaced times related to t2 and t4. Thus the MMC system should sample its signal at two different times. At the present time, the MMC system does not fully address this issue. The transient recorder STOP pulse is derived from t2 which was the earlier of t2 and t4 in the multipulse tests. Thus the transient recorder will capture both pulses as long as the second occurs within about 320 μ s of the first. Since no photodiode signal was available in the control room at the time of the installation of the MMC system, the database was not set up to recover this information.

Ideally two photodiode outputs should be available for treatment by the rest of the CAMAC hardware on normal firings. This could be accomplished either by use of a second photodiode or the use of a signal splitter if signal amplitudes are sufficient. The two outputs could then be directed to crates associated with both t2 and t4. As installed, the photodiode signals are processed

only in one crate. However, the gate pulse for the IADC in another crate has been set up to deal with a second photodiode signal. None of the software associated with the photodiode was enabled at installation.

4.4.2.2 Simulator Prefiring. When one of the Marx generators prefires, the relationship between the simulator timing signals (t0, etc.) and the simulator output signals is destroyed. If the prefire occurs after the clamps have been withdrawn, the Blumleins will be charged to some level. Under these circumstances, it is desirable that the MMC system be able to recover as much information as possible. This requires generating triggering and gating pulses by detecting the prefire and triggering the appropriate portion of the timing chain. This task is complicated by the fact that, for a prefire, the events within the timing chain are grouped according to the associated Blumlein rather than by the associated simulator timing signal. Thus, a major reorganization of the timing chain must occur automatically when a prefire is detected.

The fast signal subsystem attempts to deal with prefires by accepting secondary inputs to the timing chain at each of the trigger generators. These secondary inputs are driven by the outputs of the discriminators which process pulse charge signals from the simulator. If a pulse charge signal exceeds the threshold of the discriminator which has been set by the MMC software to one-half of the expected amplitude, an output pulse is generated by two channels of the associated discriminator; one for the leading edge, the other for the trailing edge of the pulse.

It was originally intended that the leading edge pulse would trigger those timing signals related to t0 (or t3) and the trailing edge those related to t2 (or t4), because it is the trailing edge that is related to output pulses. However, the differences in cable lengths from the simulator for the pulse charge signals and for Blumlein output signals precludes this since the output signals arrive at the CAMAC system before the trailing edge of the pulse charge signal. Thus the leading edge pulse is used as the secondary trigger for both classes of timing signals. The effect of a prefire (e.g. for the Marx charging Blumlein A) on the timing tree is shown in Figure 4.7. A prefire effectively splits off those parts of the trigger generator modules and the gate generators that are associated with Blumlein A from the rest of the tree and triggers them separately.

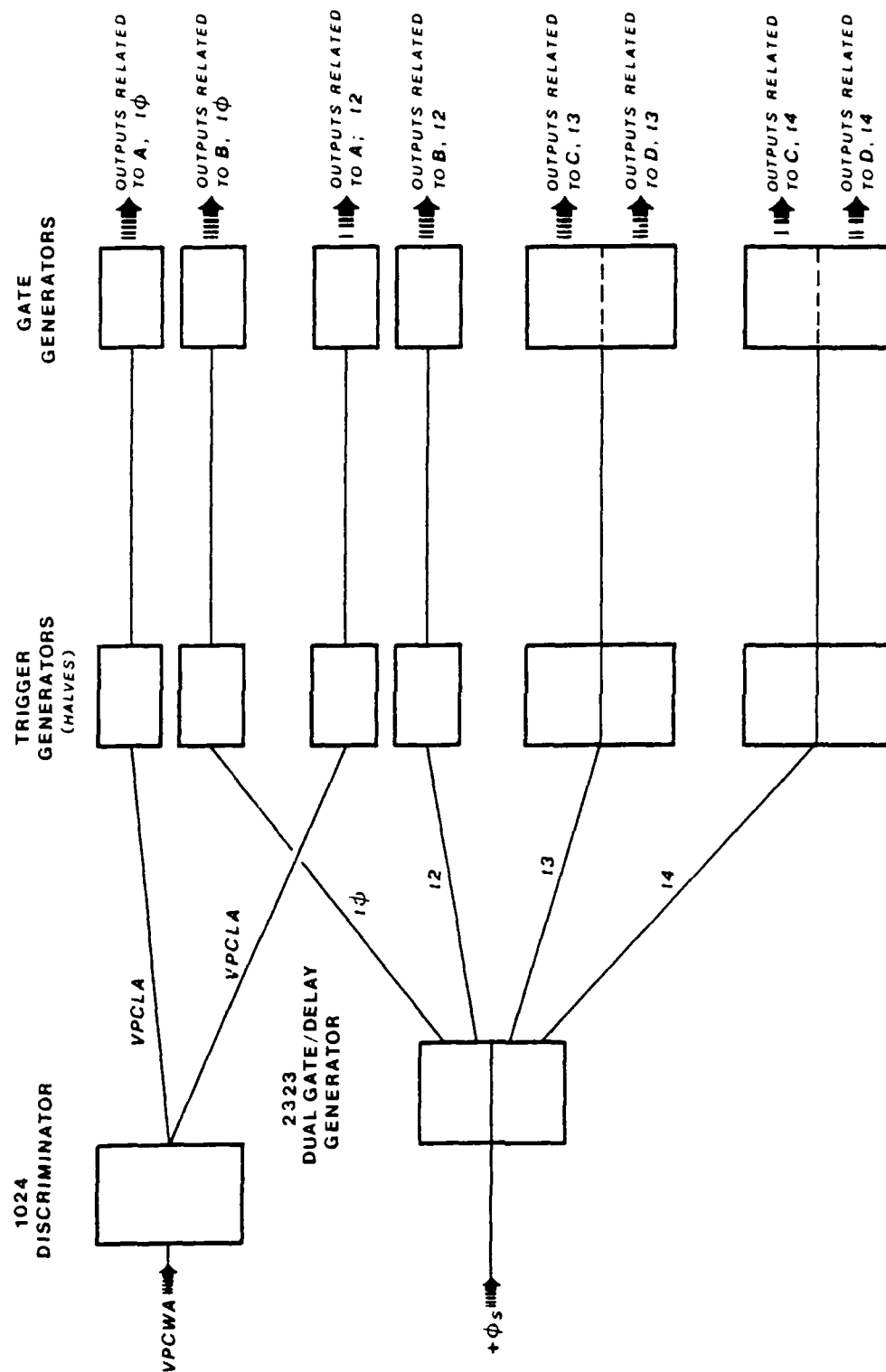


Figure 4.7. Timing tree for a prefire of simulator that is detected only on pulse charge signal associated with Blumlein A.

Unfortunately there are some signals processed by the fast signal subsystem that cannot be associated with a single Blumlein. These are the signals from the TAGs, the trigger Marxes, and the photodiode. The MMC system makes no special provision for the processing of these signals in the event of a prefire. Accordingly, since TAG1 is processed in the crate associated with Blumlein B, if a Marx generator which charges Blumlein B prefires and the MMC system detects the prefire, the timing signals for this crate will be generated at the time of the prefire and data for TAG1 will be lost even if it fires normally. A similar situation exists for the other signals in this class. Solutions to this problem are complicated and would require additional CAMAC hardware which could not be accommodated within the existing crates. Since this situation is expected to occur rarely, it would not be "cost effective" to implement any of the solutions.

Although the concept for the treatment of prefires is sound, its implementation is flawed. The system properly handles only PADC measurements for signals arriving after the leading edge of the corresponding pulse charge waveform. The difficulty lies with the timing differences between normal shots and prefires. On a normal shot, some trigger generator output pulses associated with TAGs and trigger Marxes must be generated within 1.4 μ s of the "t0" pulse available to the trigger generators. However, the leading edge of the pulse charge waveform is detected at about 4 μ s. The loss of the TAG and trigger Marx data is not too significant since it would probably be meaningless anyway, but the timing shift of more than 2.5 μ s affects all of the CAMAC modules except for the PADCs. In principle, software could correct for the effects on the transient recorders and LTDCs since software can detect a prefire and the time shift is known, but the required software was not written due to time and budget constraints. The IADCs and STDCs require a hardware solution involving a redesign of the trigger generator modules to incorporate adjustable delays in the primary trigger leg of the circuits. The addition of the software and the redesign of the trigger generators would permit recovery of all meaningful data from a prefire provided that the appropriate pulse charge signal reaches an amplitude (50%) sufficient to be detected by the discriminators.

4.4.3 Implementation.

The details of signal flow in the timing hardware are presented in Figures 4.8 and 4.9. Figure 4.8 shows all of the connections in the portion of the timing system that is used for a normal firing of the simulator. Each rectangle in the figure represents the type of CAMAC module and/or the location of the end of each cable in the system. The type of module is indicated on the top line in the rectangle, and its location is indicated by two numbers on the second line in the format "crate.station". The only exceptions to this format in Figure 4.8 are "BKPNL" which refers to the back panel of the RFI cabinet which houses the fast signal subsystem, and "RS" which refers to the resistive splitter at the STARTA output of the LeCroy 2323 module located in crate 2. The label for the terminal to which each cable is connected is listed near the associated rectangle and cable. The outputs for the trigger generator modules are indicated where the cables split from the vertical line. The signal name is listed above its associated (horizontal) cable and the cable number is listed below. Vertical cables are identified by label and number grouped together along their sides.

An abbreviated version of the portion of the timing hardware associated with prefires is shown in Figure 4.9. The trigger generator modules indicated in this figure are the same units as shown in Figure 4.8 and are placed in the same order from top to bottom. All of the trigger output connections have been omitted. They are shown in Figure 4.8. The labels "SIG" in the left-hand rectangles refer to terminals on the RFI enclosure which houses the signal conditioning cards. Figure 4.9 also shows the connections for all of the "data" signals that are associated with the outputs of the 1024 discriminators, although these are not really a part of the timing chain.

The output pulses from the gate generator modules must be set to match the timing of simulator signals. The delays for each channel must be matched to the arrival times for their associated simulator signals. The pulse width of START, STOP, and TRIGGER inputs to the CAMAC modules is not important and has been set arbitrarily to 100 ns. All of the "gate" inputs to the CAMAC modules must be matched to the length of the respective pulses from the simulator in order to optimize the accuracy of the measurements. The

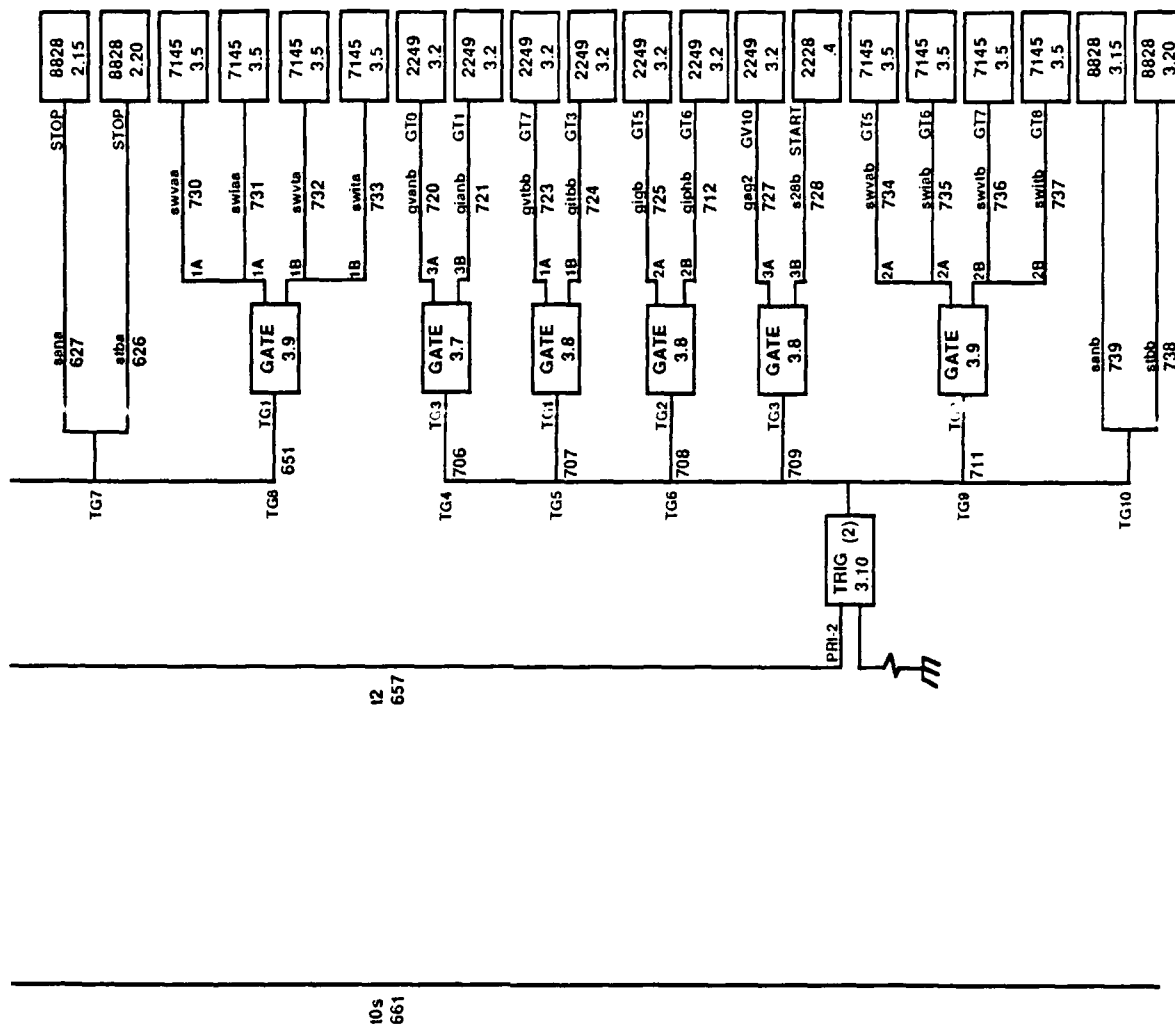


Figure 4.8(b). Diagram for normal timing signals.

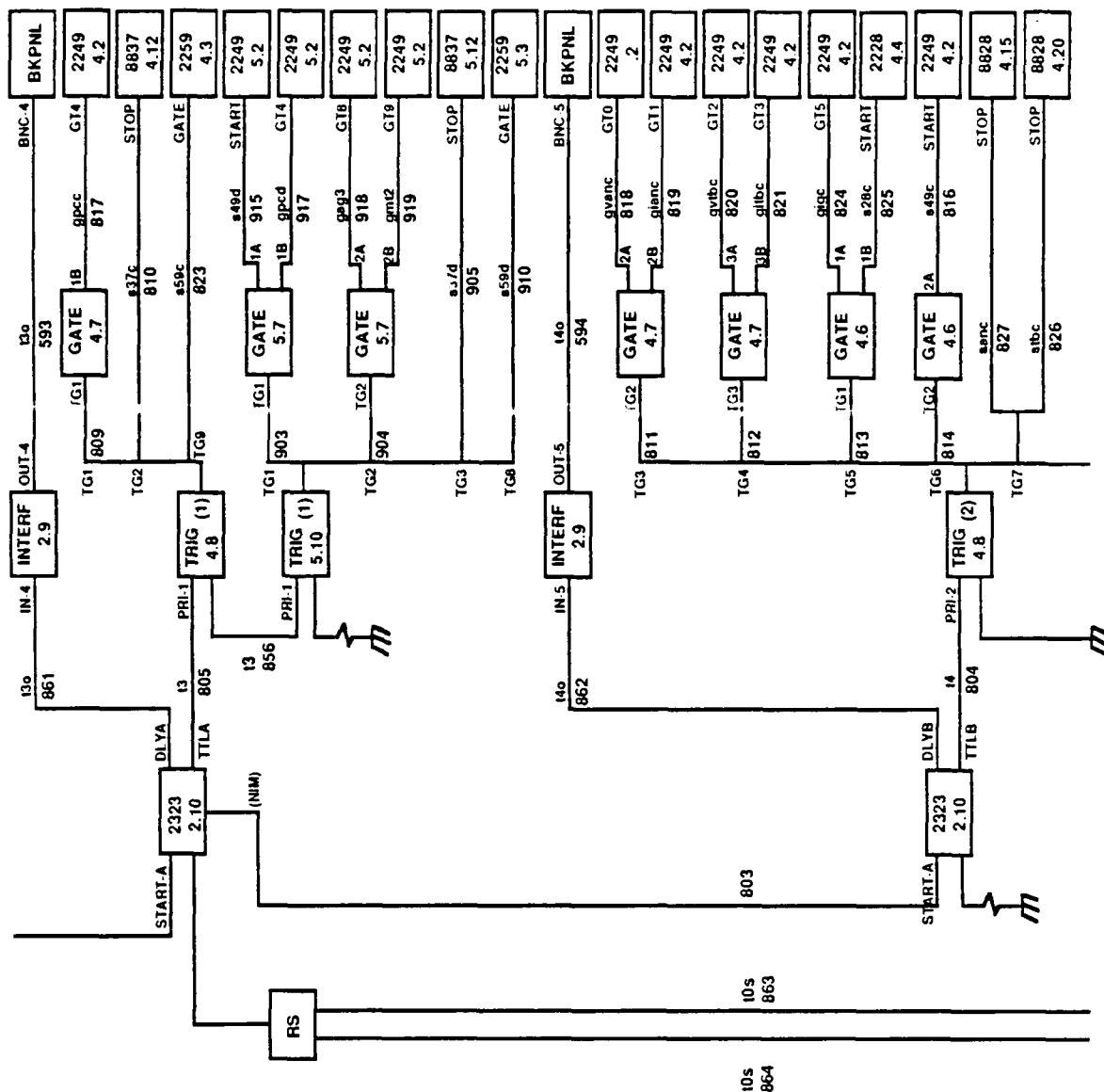


Figure 4.8(c). Diagram for normal timing signals.

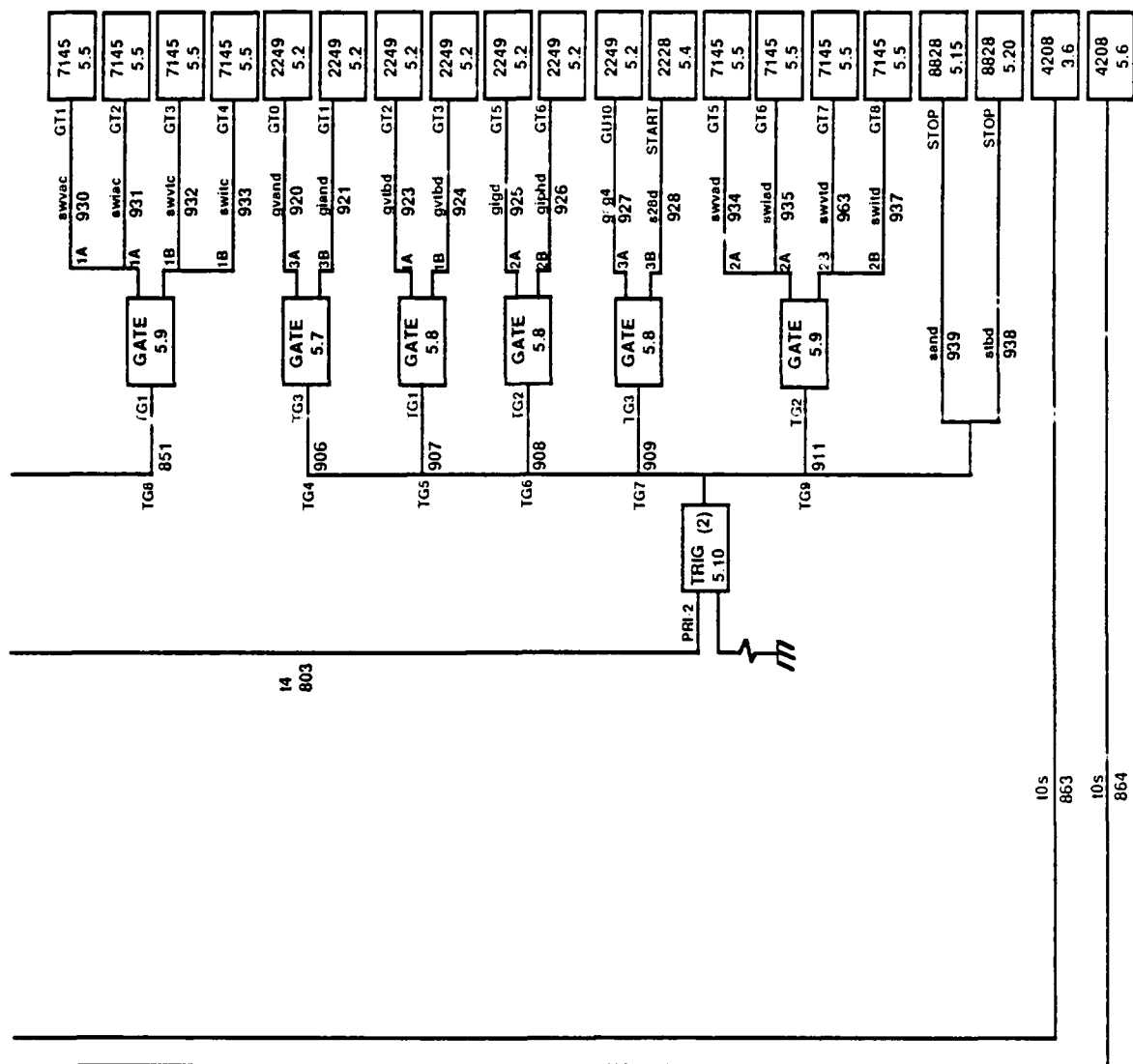


Figure 4.8(d). Diagram for normal timing signals.

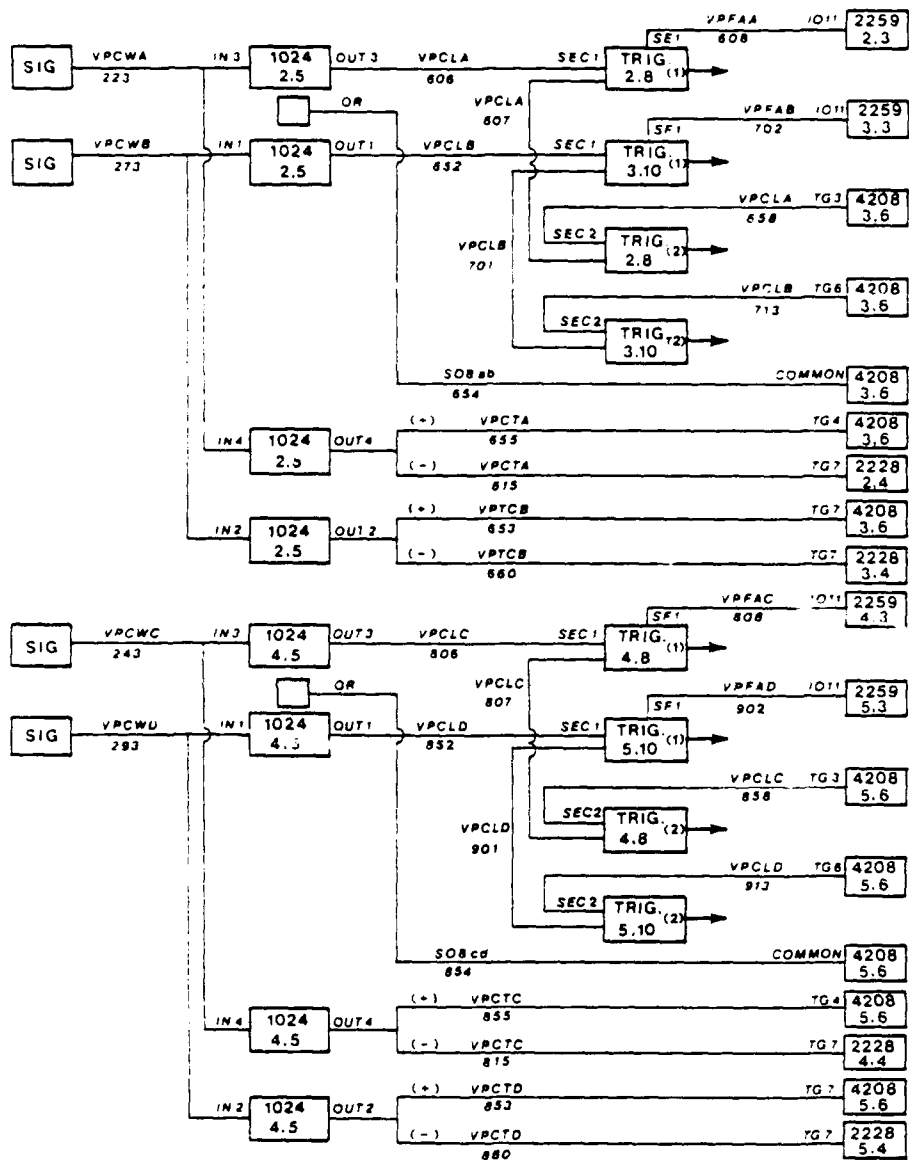


Figure 4.9. Diagram for prefire timing signals.

gate channels used to switch the analog multiplexing system, discussed in Section 4.6 must be set to at least 500 ns.

The end result of the timing system is shown in Figure 4.10. This figure indicates the relationship between the various timing signals and simulator signals for a normal firing of crate 3. This crate processes signals from Blumlein B as well as the TAGs and trigger Marx associated with the single pulse mode. The s49b signal is a START pulse not a gate. Its length is not significant. The acceptable windows for the 2249 and 2228 modules is indicated as dashed extensions of the START pulses. The delayed tube and anode current signals are shown as dashed curves.

4.5 TIMING MEASUREMENTS.

Timing measurements are made on the simulator signals by both long interval time to digital converters (LTDCs) and short interval time to digital converters (STDCs). The STDCs do not have sufficient dynamic range (1 μ s) to measure all of the event times of importance in the simulator. Therefore, their use is restricted to signals which are associated with the chain of events that directly culminates in a Blumlein output pulse such as TAG2, pulse charge trailing edge, tube voltage, etc. Those signals which are associated with the firing of the main Marx generators such as TAG1, trigger Marx 1, and pulse charge leading edge are analyzed by the LTDCs.

Two LTDCs are used in the fast signal subsystem. Each measures the Marx related signals associated with a Blumlein pair. Specifically, each analyzes a Marx TAG (1 or 3), a trigger Marx, and the leading and trailing edges of two pulse charge waveforms. The MMC software subsystem requires that there be a traceable trail of timing events in each TDC which leads back to t_0 . Since the LTDCs are triggered from a logical OR of pulse charge leading edges in order to detect prefires, the start times of these modules is not known. In order to satisfy the requirements of MMC, the MMC synchronized t_0 (t_0 s) is fed to both LTDCs as data. This allows MMC to relate all signals fed to the LTDCs to t_0 s even though it is not the triggering event. There is a known relationship between t_0 s and T0OUT which is used to fire the simulator. Since five of the seven signals processed by each LTDC are positive polarity (TTL), these modules are strapped for positive pulses, even though the STDCs require negative signals. It was easier to invert the four remaining

LTDC signals on the signal conditioning cards than to invert the other ten signals on the fronts of the CAMAC modules.

One STDC is used for each Blumlein. Since the STDCs do not have the dynamic range to measure the arrival times of t_0 s and Blumlein outputs, another approach must be used to enable MMC to relate times measured by the STDCs to t_0 . The pulse charge trailing edge signals, which are related to the closing of the Blumlein output switches and hence to the output pulses are fed to both a LTDC and a STDC. This allows MMC to calculate the relative timing of the two types of TDC to relate all times to t_0 s on a normal shot, and all times associated with a single Blumlein in the event of a prefire. The trailing edge signals were selected for this purpose because they occur within the dynamic range of the STDCs, they are normally input to the LTDCs anyway, and they have sufficient amplitude to drive both TDC inputs.

The discriminator modules are used to obtain fast rising signals suitable for use with the TDCs from the slowly rising pulse charge waveforms. In addition, the discriminators permit the leading and trailing edge timing signals to be related to a constant fraction of the expected pulse charge voltage as the Marx charge voltage is varied.

4.6 ANALOG MULTIPLEXERS.

In order to reduce the number of expensive transient recorders necessary to service the desired number of simulator output signals, an analog multiplexing scheme has been incorporated into the fast signal subsystem. One half of the multiplexed signals are fed into commercially available analog delay lines which introduce a 500 ns delay that is accompanied by a 12 db. The other half of the signals are attenuated by 12 db in the signal conditioning system so that the resolution of the digitization process is nearly the same for all of the signals.

Pairs of analog signals (one delayed and one not delayed) are delivered to adjacent inputs to analog switches (Phillips 7145) mounted in CAMAC modules. These analog switches are internally strapped so that in each pair of inputs, one is "normally open" and one is "normally closed". Identical gate pulses are fed into each channel pair from a gate generator module output so that a single gate channel pulse switches between two analog inputs.

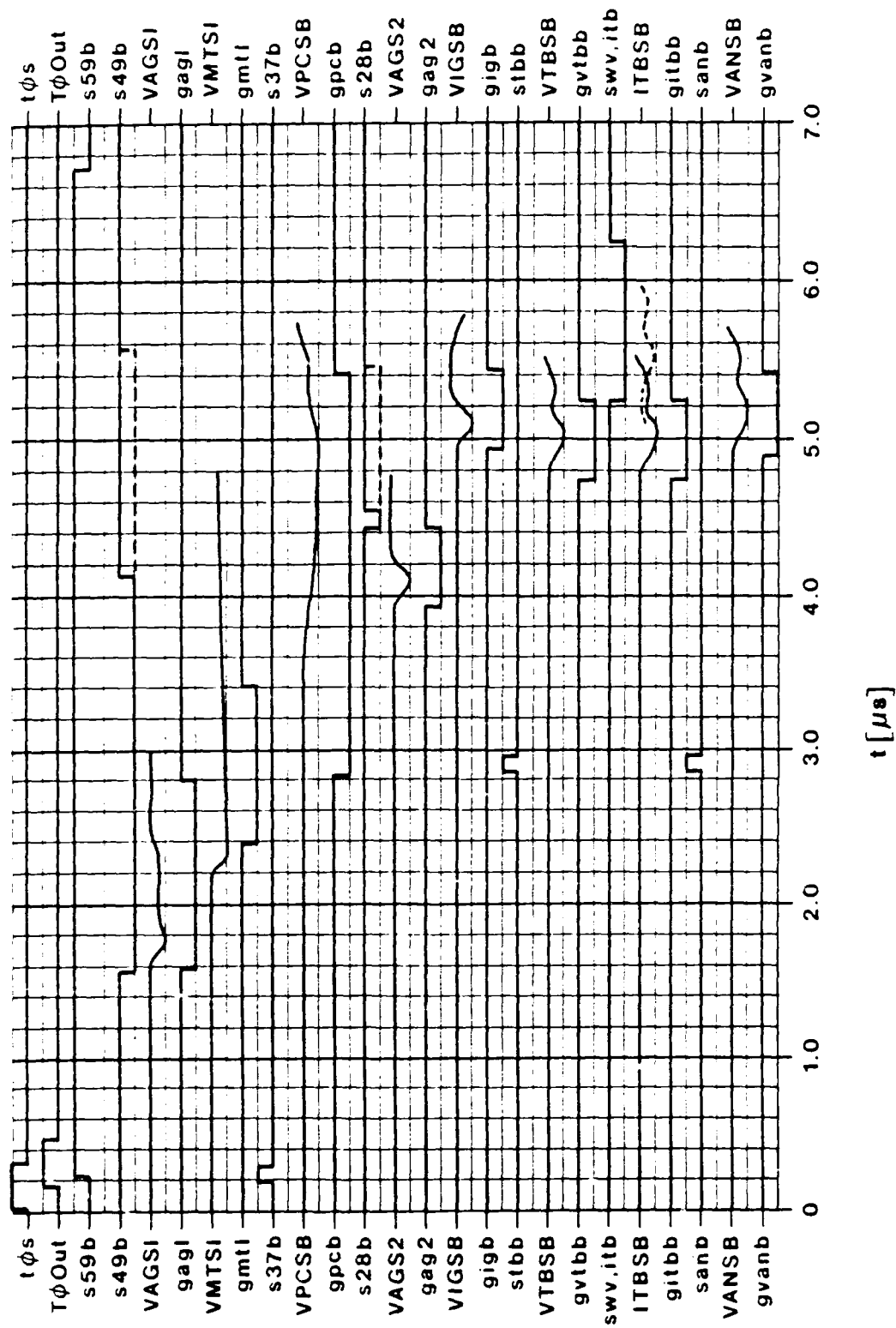


Figure 4.10. Timing and simulator signals associated with Blumlein B.

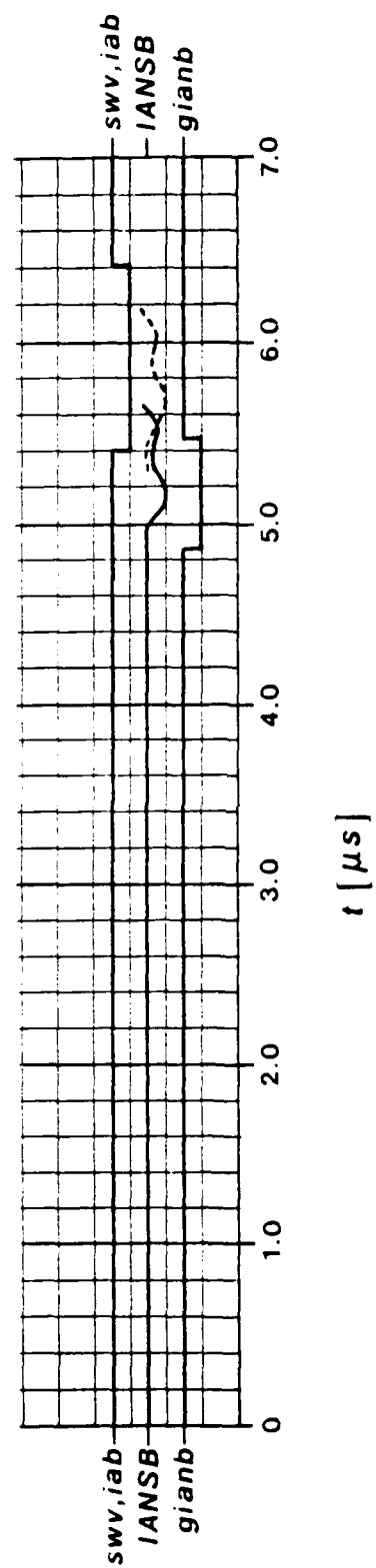


Figure 4.10 (continued).

Unfortunately the outputs of the analog switches are shorted when inactive rather than open. Thus the outputs of pairs of channels cannot be paralleled directly to form the desired SPDT switch. Passive combiners are used to sum pairs of outputs thus completing the SPDT switching function. These combiners provide isolation between the inputs so that the inactive, shorted outputs of the switches do not affect the active signals.

A block diagram of the analog multiplexing system is shown in Figure 4.11. This figure uses the same format as used in Figures 4.8 and 4.9 described in Section 4.4.3 above.

The analog delay lines were selected when multiplexing four signals per transient recorder was under consideration. The choice was not reviewed when the number was reduced to two signals per transient recorder. The HDL staff has suggested that the delay lines be replaced with $1\ \mu\text{s}$ units which would increase the temporal window for each signal. This is an excellent suggestion and can be readily accommodated with minor changes to delay times in the gate generators, and data in the calibration file. However, the suggestion has not been implemented at this time.

4.7 INSTALLATION.

4.7.1 Setup.

During the installation of the MMC system, the attenuators, inverters, terminators, pulse delays, pulse widths, and hardware offsets within the system were set to values that were appropriate to the data accumulated during the installation session. Since this data was limited, the settings may prove less than optimal.

Ideally, the settings within the fast signal subsystem should be calculated from a database which includes polarity, amplitude, time of arrival, width, and temporal integral of each signal monitored by the system for several simulator firings at each of several Marx charge voltages. This would permit allowances for statistical variation, nonproportionality, and nonlinearity in each of these signal attributes. Since the system is designed to monitor 31 signals, each of which is split either three or four ways, this is a formidable task which was not accomplished during installation of the system. During installation approximately 60% of the PADC signals were monitored with a Tektronix digital oscilloscope. These mea-

surements included at least one of every type of signal except for the photodiode which was not available. All of the data used in the setup of the system was obtained at a charge voltage of 90 kV, although some shots at other voltages were fired. Signals from TAG3, TAG4, and trigger Marx 2 were not measured, and the corresponding signal conditioning boards were not installed.

Inverters were enabled as appropriate to the polarity of all of the signals presently monitored. Attenuator settings were calculated from the measured signal amplitudes and temporal integrals under the assumptions that the signal amplitudes are proportional to Marx charge voltage and that the maximum dc charge voltage is 120 kV. Pulse amplitudes for the TAGs and trigger Marxes were assumed constant. A 15% safety margin was included between maximum calculated signal amplitude and full scale for the CA-MAC modules. Full scale for the IADCs was assumed to be 6 nV-s thus allowing 6.8 nV-s for IADC pedestal (see Section 4.3.2). All unused outputs of the Tapoff Chassis and the signal conditioning boards were terminated appropriately. The hardware offset voltages for the transient recorders were set to permit 30% voltage reversal to be recorded without saturation. Timing pulse delays were set with a small allowance for statistical variations in arrival times, and gate pulse widths were set to overlap the main portion of each signal excluding ringing from the measurements. Unfortunately, the maximum available gate width was not sufficient to overlap the trailing edge of the pulse charge waveforms.

Most adjustments to software parameters are most appropriately classified as a part of the calibration of the system and are described in Section 4.9. Two items that are software adjustments: setting the discriminator thresholds, and the display windows for the transient recorder data.

The thresholds for the discriminators are set through a data word in the configuration file. They were set at installation by measuring the amplitude of the pulse charge waveforms and measuring the threshold of the discriminators by injecting a pulse into the discriminator input and checking for output pulses from the discriminator. The setup data for the discriminators was then set to obtain output pulses at one-half of the measured pulse charge signal amplitude. The MMC software subsystem assumes that the pulse charge amplitude scales proportionally with main Marx generator charge voltage.

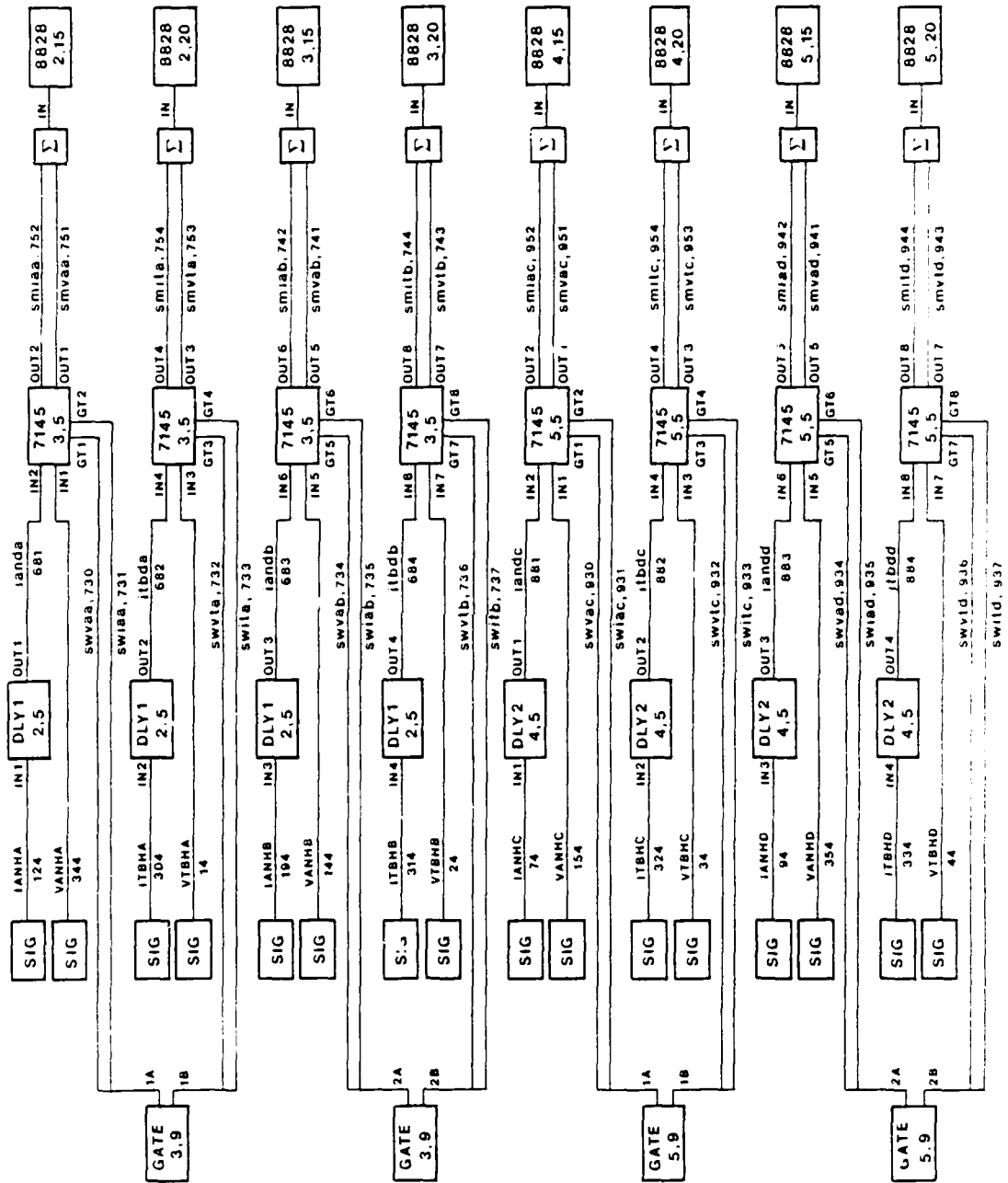


Figure 4.11. Diagram for analog multiplexing signals.

The display windows for the multiplexed Blumlein output signals are set in the calibration file. The transition from one frame to the next was set to correspond to the transition in the analog signals, and the width of the window was set to display the desired information.

4.7.2 Chronology.

Installation of the fast signal subsystem was performed during three "windows" spaced over the six months from mid-September 1987 to mid-March 1988.

The first window ranged from 16 September 1987 through 9 October 1987. This installation included the complete setup of the computer system as well as a great deal of work on both the slow signal and software subsystems. The physical installation of the fast signal subsystem was completed, and testing was performed during the week of 5 October through 9 October. The subsystem had been shipped with all of the internal cabling complete. The signal conditioning boards were set in accordance with information on expected signal amplitudes provided by the HDL staff. Basic timing information was obtained from shots fired on 5, 6, and 7 October. Gate and trigger timings were calculated and set based upon this data.

The thermal impact of power dissipation within the subsystem was not anticipated since the subsystem was operated for only a limited time with a complete set of CAMAC modules installed at PSI. On 7 October a massive failure of the Jordan gate generator modules occurred which may have been related to temperature. The modules were removed from the subsystem, and a major reconfiguration of the timing portion of the subsystem was designed and installed. This reconfiguration limited the subsystem's reliance on the gate generator modules. Unfortunately, little time remained during the window and the subsystem was left only with most of the transient recorders functioning (including analog multiplexing), and indications that the peak reading ADCs were acquiring data.

Repairs were made to the gate generator modules, and problems were discovered in the CAMAC cable assemblies prior to the second installation window. The second window ran from 30 November through 18 December. During this window, all of the CAMAC cable assemblies were reterminated and the gate generator modules were reinstalled. A great deal of data was accu-

mulated on simulator signals which permitted calculation of peak amplitudes, temporal integrals, and arrival times for most of the signals being processed by the subsystem. At the conclusion of the window, all delay times had been set according to the best information available, and peak amplitude, transient recorder, and timing data was being acquired by MMC and printed in the shot document.

During the third installation window which ran from 29 February 1988 through 11 March 1988, an attempt was made to calibrate the subsystem. This effort is described in Section 4.8. below. This installation window was shared with other users of the simulator which involved some loss of efficiency. All of the signals available were enabled in hardware. The signals that were not available included those from TAG3, TAG4, and trigger Marx 2 which are associated with the multipulse mode of operation, anode voltage on Blumleins A and D which do not have monitors installed, and the control room photodiode was not operational. All portions of the fast signal subsystem were operational with the exception of the integrating ADCs, though the calibration left a great deal to be desired. The TIG signals which were added in hardware were not enabled in software so that no data is being acquired for them by MMC.

4.8 CALIBRATION.

The incorporation of a computer into a data acquisition system gives the user a great deal of flexibility in correcting the data for a wide variety of phenomena which distort or corrupt the information. At this time, the MMC software subsystem allows for only multiplicative (scale factor) and additive (offset) constants in each CAMAC data channel in the fast signal subsystem. These calibration constants are to be used to correct for the major effects associated with the CAMAC instruments, attenuations, cable lengths, and monitor sensitivities.

There are four classes of calibration "constants" each having different origins and thus requiring different approaches for their determination. Amplitude offsets result from effects within the CAMAC modules themselves. The ADCs must make their measurements of the analog signals and hold them until the conversion into digital data is complete. Retention is not perfect and a signal is intentionally added by the instrument to ensure that measured value does not approach zero when the units are gated without an analog input. Temporal offsets result principally from sources external to the CAMAC modules; specifically from

delays associated with cable lengths. The fast signal subsystem has been constructed with equal cable lengths for the analog signals. However, some "daisy chaining" is employed in the timing system which introduces crate-to-crate timing differences of a few nanoseconds. Amplitude scale factors or sensitivities result from sources both external to and within the CAMAC modules. The combined attenuation of the signal tapoffs and signal conditioning boards, as well as the sensitivities of the monitors and the CAMAC modules determine the overall calibration factor. The temporal scale factors for the TDCs are the result of internal effects in the modules.

It should be noted that the "calibration" of the CAMAC modules themselves is only a small part of the overall calibration problem. The signal tapoffs and signal conditioning boards employ components with low voltage and temperature coefficients, but these components are not high precision components nor have they been "trimmed" to obtain precise values. It has been assumed that the actual attenuations would be determined and incorporated into the MMC database along with the sensitivities of the individual modules.

It is possible to approach the calibration of the fast signal subsystem on a component by component basis, measuring the attenuation and time delay associated with each component in each data channel in the subsystem and combining the results of these measurements in order to determine the overall calibration constants required. However, a simpler approach is to inject a large amplitude signal (up to approximately 1 kV) into the Tapoff Chassis terminals and measure the output data from the CAMAC modules to determine the overall calibration factors in one step. If the amplitude, effective pulse length, and timing relative to t_0 of the fast signal subsystem were known, all of the effects associated with the scale factors of the associated CAMAC data channels could be determined except for the sensitivities of the monitors. Both the amplitude and temporal offsets would have to be determined separately.

A triggered, high amplitude pulsed source was not available during installation. Consequently, an attempt was made to calibrate the subsystem in two steps with available sources. This attempt was not very successful but indicated the problems which must be addressed in order to complete a successful calibration.

4.8.1 Amplitude Offsets.

Amplitude offsets for the PADCs and IADCs cannot be determined by gating the modules without analog input signals and reading the associated digital data for each channel of each module. The response of the ADCs to an input pulse has the general form shown in Figure 4.12. Taking the zero input signal reading as the offset can result in substantial errors in interpreting subsequent measurements. The offset must be calculated by taking a series of measurements at different amplitudes within the linear response of the module and using linear regression to determine the best values for slope and offset. In addition, there is a wide statistical variation in measurements made by the IADCs. Therefore, several measurements must be made at each value of input signal in order to determine the calibration constants. At the present time, this data must be accumulated and analyzed by hand using the utility routine FTEST and a calculator or computer to perform the linear regression calculation. Of course, it would be possible to automate this process.

The amplitude offsets calculated for the PADCs were modest compared to the full scale range of the units, and the overall calibration was moderately successful for these units. However, offsets for the IADCs were generally large and comparable to full scale for the longer gate widths. Pedestals for the IADCs must be adjusted prior to calibration which was not done during installation because the appropriate software was not available. Measured data from the IADCs must be available in "real time" while the adjustment is performed.

Amplitude offsets for the transient recorders are determined automatically by the MMC software subsystem. This is accomplished by assuming that a fixed number of data points at the beginning of the time interval specified in the calibration file constitute a baseline or zero amplitude signal. MMC warns the operator if this data is not sufficiently constant for a "good" determination of the offset, but still uses the average value calculated.

4.8.2 Temporal Scale Factors.

The LTDCs have a fixed temporal sensitivity of 1 ns per count which results from interpolation of a crystal controlled clock. As long as these units are functioning normally, their accuracy is more than adequate for the required measurements.

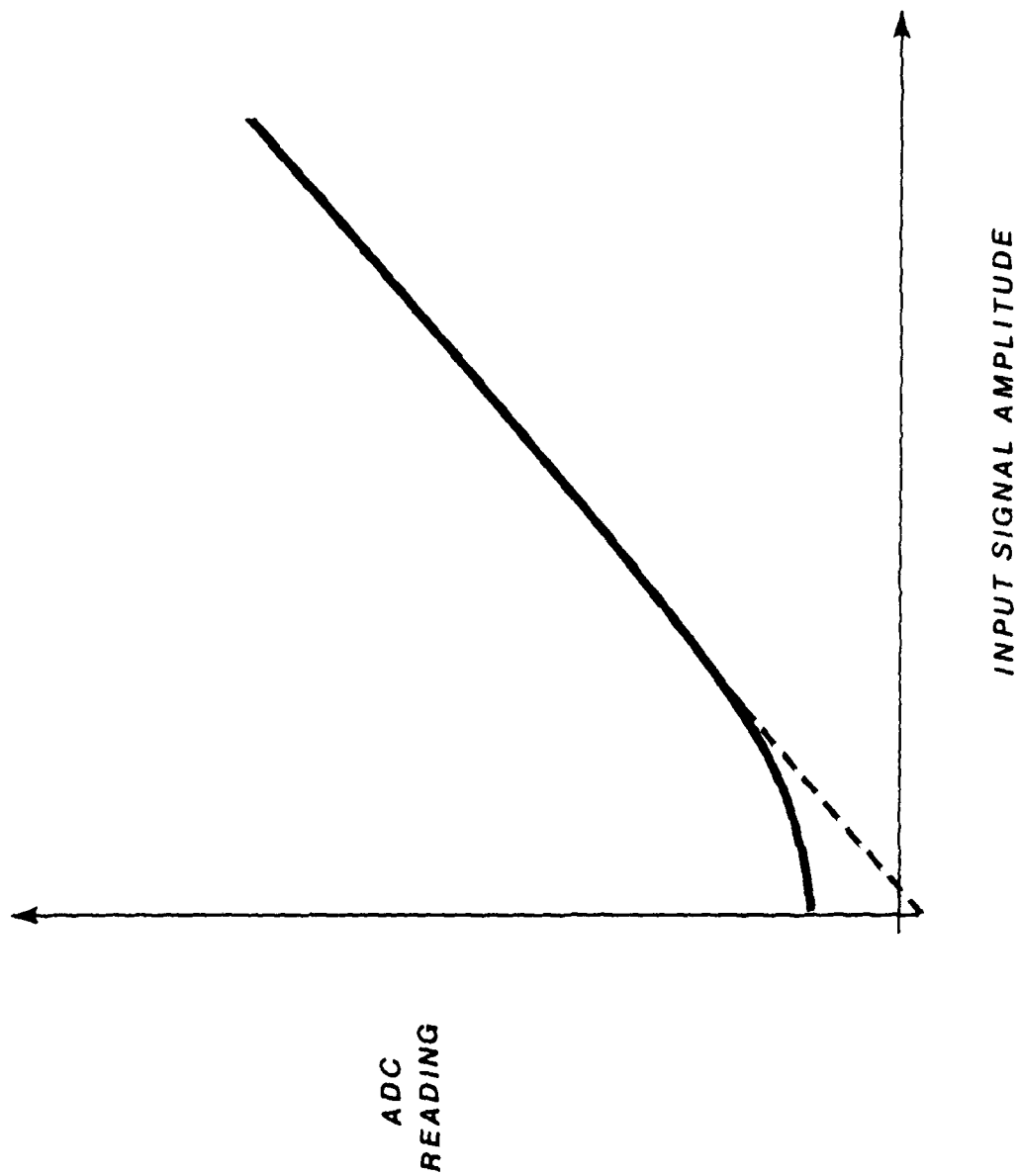


Figure 4.12. ADC response.

The STDCs have an adjustable temporal sensitivity that is determined by switch settings and potentiometer adjustments on the side of the module. Internally, a reference current is used with integrating capacitors to make the measurement, and the adjustment determines the magnitude of the reference. These units were adjusted to approximately 0.5 ns per count at PSI. During installation, the STDCs were calibrated by injecting a pair of pulses with a spacing of 500 ns into two inputs within the 1 μ s measurement window of each STDC. The utility routine FTEST was used to read the number of counts recorded, and the appropriate change to the module scale factor was calculated and entered into the MMC database.

4.8.3 Temporal Offsets.

Provision has been made in the MMC software subsystem for the incorporation of temporal offsets (delays) into the MMC database. To utilize this feature of MMC, the appropriate reference time(s) must be determined, the delays both external to and within the fast signal subsystem must be measured and calculated offsets must be entered into the MMC database.

Times within the fast signal subsystem are measured with respect to t_0 s as delivered to the LTDCs. The simulator reference time was taken as the time at which T0OUT is delivered to the BNC connector on the rear panel of the RFI cabinet which houses the subsystem. A time difference of 162 ns was measured directly.

Cable delays from the simulator to the CAMAC modules were determined in two steps. The pulse propagation time from the rear of the Tapoff Chassis to the TDCs was measured directly for one signal channel. Since all cable lengths within the subsystem are equal within one inch, only one channel was measured. The time delay of 113 ns measured at half amplitude includes the degradation of the pulse risetime within the signal conditioning system. The cable delays from the rear of the tap-off chassis to the simulator were determined by time domain reflectometry. The TIG cable lengths are uncertain because of an exceptionally good impedance match at the monitor. The throughput delay of the discriminator modules was not measured but was assumed to be zero. The throughput delays of the analog delay lines were also not measured but were assumed to be 500 ns. The calculated net delays were entered into the MMC calibration file, but the shot

document was not analyzed to determine if the delays were correct.

4.8.4 Amplitude Scale Factors.

As noted above, the amplitude calibration of the fast signal subsystem is a great deal more complicated than knowing the simulator monitor sensitivities and the sensitivities of the CAMAC modules. There are a lot of components between the inputs to the Tapoff Chassis and the inputs to the CAMAC modules. These include the signal tapoffs themselves, and the preattenuator, main attenuator, main inverter, splitter, individual attenuators, and terminators of the signal conditioning boards. Each of these components has an effect on the amplitude of the signal transmitted to the inputs of the CAMAC modules. The overall attenuation factor or the sensitivity of each channel of the fast signal subsystem can be determined from individual measurements on each individual component, or the overall sensitivity can be determined by injecting a signal of appropriate amplitude and polarity into a channel of the tap-off chassis.

During installation, an attempt was made to calibrate the ADC and transient recorder signal channels. Since a triggerable, high amplitude source was not available, the calibration had to be performed in two steps. The first step was to measure the total attenuation between the rear of the tap-off chassis and the CAMAC modules. The second step was to calibrate the CAMAC modules themselves. The results of these measurements were then combined with monitor sensitivity information provided by the HDL staff to obtain the overall calibration constants for the fast signal subsystem.

4.8.4.1 Signal Conditioning Channels. The tap-offs and signal conditioning circuits were calibrated by injecting a pulse into the rear of the tap-off chassis in place of the signals coming from the simulator. The amplitude of the injected pulse was measured before and after each channel was calibrated. The channels were calibrated with the same attenuator setting used in simulator operation. However, the main inverter was frequently restrapped to permit calibration with pulses of opposite polarity to those generated by the simulator. Since the inverter transformer is always in the circuit, regardless of the polarity selected, this change should not have affected the calibration of any channel. This portion of the cal-

ibration is expected to be accurate to the + 2% reading accuracy of the digital scope.

4.8.4.2 Analog to Digital Converters. An attempt to calibrate the CAMAC ADCs was performed by injecting signals into the modules and using the utility routine FTEST to access the results of the measurements. The output of two signal sources was split eight ways with MiniCircuits Lab passive splitter/combiners. The eight outputs were measured individually and all unused outputs were terminated. A digital delay generator was used to position the calibration pulses within the gated temporal window when the appropriate ADC channel was active. A calibration file (LEE4) which contained unity sensor gain and zero sensor bias for all ADC channels was used with FTEST so that raw data was read from the ADCs.

Eight separate measurements were made at each of three signal amplitudes on each IADC channel. The signal amplitudes were approximately 80%, 40%, and 20% of the full scale range of the IADCs. The pulse width was fixed at 50 ns FWHM. Unfortunately, no measurement of the baseline level of the signal was made. Since the gate times of some of the channels is 2.5 μ s, the baseline level must be negligible compared with 2% of the pulse amplitude to prevent it from affecting the measurement. Ideally, the IADCs should also be calibrated at several different pulse lengths and several different times with respect to the appropriate gate pulses. Results of the eight measurements were averaged, and the averages were subjected to linear regression analysis to determine the sensor gain and sensor bias.

A shot document generated after a simulator firing with the new calibration constants yielded nonsensical results for the IADC channels. Although it is possible that the problem lies in the software, it is more probable that the IADCs require adjustment of their pedestals and a more careful calibration to be useful.

The procedure used to calibrate the IADCs was repeated for the PADCs but with a different signal source since the one used in the IADC calibration could not produce pulses near the full scale range of the PADCs. Overall accuracy of calibration of the PADCs, as determined by comparison of values printed

in a Shot Document with those obtained on the same shot by the data room data acquisition system, was approximately + 20%. This is a considerable improvement over the results of the IADC calibration, but is still far short of the accuracy required for the system to be useful. The most probable cause of discrepancy is the signal source used in calibration of the PADCs. The pulse used for calibration was approximately 500 ns FWHM with a 15 ns risetime and a droop of 20%. LeCroy recommends that the PADC not be used with pulse risetimes less than 50 ns. This and the pulse droop raise uncertainties about accuracy of measurement of the effective input signal amplitude. Risetimes of pulses delivered to the PADCs by the simulator are longer than the required minimum of 50 ns.

4.8.4.3 Transient Recorders and the Analog Signal Multi-plexing System. Transient recorders were calibrated together with the appropriate analog signal multiplexing system. Signals were injected directly into the LeCroy 8837s which record the pulse charge waveforms, which are not multiplexed. Signals were injected simultaneously into the "voltage" and "current" inputs of the analog signal multiplexing system, thus measuring the attenuation of the analog switches, analog delay lines, and passive combiners as well as the sensitivity of the transient recorders themselves. MMC was used to generate a Shot Document for each of three signal levels for each data channel. The signal amplitudes were measured from the shot document, and linear regression analysis was used to determine the calibration constants. The overall accuracy of the result of the calibration was not assessed.

4.9 SUMMARY.

The fast signal subsystem of the Machine Monitor and Control system samples thirty-one diagnostic signals produced by the Aurora simulator and analyzes them with CAMAC instruments. Four types of CAMAC modules are used to analyze the signals and convert the resulting measurements into digital data that can be acquired and processed by the MMC software package. These modules are integrating analog to digital converters (IADCs), peak reading analog to digital converters (PADCs), time to digital converters (TDCs), and transient recorders.

After the March 1988 installation effort, all but six of the thirty-one signals were being processed by the CAMAC modules of the subsystem. The remaining six signals include three that are not presently generated by the simulator (two anode voltages and the photodiode), and three that are associated only with the multipulse mode of operation (TAGs 3 and 4 and trigger Marx 2). Provisions have been made for the processing of these signals when they become available. In addition, the four TIG signals associated with the Blumlein master switches are being processed by the CAMAC hardware, but are not enabled in the MMC software so that the data is not being acquired and documented.

All of the CAMAC modules with the exception of the IADCs are performing their intended tasks. The situation with the IADCs has not been resolved, but most probably requires adjustment of each individual input channel pedestal and calibration of the units.

Calibration of the subsystem is barely satisfactory. The PADCs appear accurate only within $\pm 20\%$ and the accuracy of the calibration of the transient recorders is not known.

Calibration of the TDCs is acceptable, and adjustments have been made for all measured subsystem and simulator delays. Throughput delays of the Discriminator modules and the analog delay lines were not measured. The delay lines were assumed to have their "nameplate" values of 500 ns. The performance of the MMC software subsystem in calculating all of the simulator timings was not evaluated.

Documents detailing the fast signal subsystem have been prepared including manuals for the PSI designed CAMAC modules of the subsystem. The documentation includes circuit diagrams, block diagrams, and SYMPHONY spreadsheets to assist in understanding, modifying, and maintaining the subsystem. The spreadsheets have been included in both printed and computer readable form and include formulas for calculating attenuator settings, strapping options, and gate generator settings.

The performance of the fast signal subsystem in the multipulse operating mode has not been evaluated. Performing the simulator modifications for the multipulse mode solely to test the MMC system is not justifiable.

SECTION 5

SLOW SIGNAL SUBSYSTEM

5.1 SLOW SIGNAL HARDWARE OVERVIEW.

This section concerns the slow signal portion of the MMC system. Conceptually, this is defined as hardware which measures "quasi" DC (slow) data channels or controls various simulator functions. The slow signal hardware consists of the following major subsystems:

Section	Title
5.2	Gas Pressure Measurement
5.3	Marx Charging Monitors
5.4	Blumlein Oil Switch Position Measurement
5.5	Vacuum Measurement
5.6	TAG/Trigger Marx Charge Voltage Monitors
5.7	Digital/Logical Signals
5.8	Signal Transmission System
5.9	Slow Signal CAMAC Cabinet

Each of these are covered in detail in the indicated section.

The slow signal hardware incorporated into the MMC system allows easy measurement and recording of important simulator parameters. To provide increased accuracy and reliability of these measurements, new transducers were provided for most channels. Existing monitors were left undisturbed and the new monitors were simply placed in parallel with the existing ones.

This method left the existing measurement system intact, minimizing both risk and operational downtime (as the old system can serve as back-up).

The Aurora simulator generates intense RFI/EMI fields. This poses a serious problem for measurement of low voltage signals distributed throughout the facility. Extensive measures were implemented in the design to prevent damage to electronic components during simulator operation.

A gas pressure measurement system was provided to more accurately monitor the various simulator pressure parameters. The transducers provided are referenced to absolute pressure rather than ambient for increased overall accuracy in reproducing simulator gas pressure set-

tings. See Section 5.2 for detailed information on this hardware.

Charging monitors for voltage and current were provided for all four Marx generators. Because a bipolar charging scheme is implemented in this Marx design, eight voltage and current channels are required. Separate voltage monitors were provided for the four bipolar operator console charge meters. This avoided a ground-loop which would affect measurement accuracy. The monitor resistors selected were chosen for long-term stability and low temperature coefficient. It was determined that charging currents must be measured through the high voltage leads, therefore magnetic amplifier current monitors were selected. This method placed active electronics near Marx charging leads and required considerable care in the final design to protect the monitoring circuits from damage during simulator operation. See Section 5.3 for additional information on this hardware.

A Blumlein oil switch position monitoring system was provided to allow increased accuracy and ease in setting the switch spacings. Linear potentiometers were selected as the position transducers because of their mechanical and electrical ruggedness. A digital readout panel completely separate from the MMC computer provides for easy operator access to electrode position information even when the computer is off. The readouts are calibrated in inches and are as accurate as the present hydraulic system allows. See Section 5.4 for a complete hardware description of the Blumlein oil switch position monitoring subsystem.

Vacuum monitors and associated readouts were provided for all four output tubes and anode regions. Cold cathode gauges were selected for increased reliability in the intense RFI/EMI/ radiation environment the simulator creates during its operation. This type of gauge readout can be remotely located far from its measurement transducer unlike most ion gauges. This prevents exposure of the sensitive readout electronics to damaging radiation and electric/magnetic fields. Additional filtering was also incorporated to further increase immunity to transients coupled into the interconnect cable. The chart recorder output was electrically conditioned to allow MMC monitoring of vacuum pressures. Dual setpoint

gauges were provided to allow their use as interlocks in future simulator control upgrades. See Section 5.5 for vacuum monitoring subsystem details.

TAG and trigger Marx charge voltages are monitored by MMC via the existing simulator monitor cables. See Section 5.6 for further information.

While not currently utilized, the hardware provides for computer control of up to 96 digital channels. Monitoring of up to 48 digital inputs is also provided. Several of the input channels are currently used to allow automatic synchronization of MMC and the existing simulator control system. See Section 5.7 for details.

To protect both the voltage measurement electronics and the computer system, great care was taken in the design and construction of interconnect and signal conditioning hardware. Further measures were taken to provide for future expansion should the need arise. See Sections 5.8 and 5.9 for hardware descriptions.

5.2 GAS PRESSURE MEASUREMENT HARDWARE DESCRIPTION.

This section covers the gas pressure measurement hardware installed for the MMC system.

To remotely measure simulator gas pressures via computer, the transducer converts the pressure being measured to a low voltage signal with a low source impedance. The SenSym Model LX18 series pressure transducers are fully signal conditioned devices with temperature compensation and absolute pressure referenced outputs. These transducers are mounted in a EMI/RFI shielded Hoffman enclosure with extensive filtering/protection circuitry incorporated on all input/output lines. A stable pressure reference with solenoid controlled valves allows computer/sensor calibration checks to be performed regularly.

5.2.1 Gas Pressure Transducer Hoffman Box.

The gas transducer Hoffman box is located close to the existing master gas panel. Hookup is made to the existing system via a 1/8 inch nylon gas line. This provides electrical isolation and some pressure damping. Connection to the MMC slow signal transmission system is made via a single multiconductor shielded twisted-pair cable terminated in MS (military style screw shell) connectors. Incoming electrical power is double filtered

with additional protection provided in the form of varistors for transient clamping.

Two ranges of pressure transducers were used for increased resolution. SenSym Model LX1830 0-300 psia transducers were used for reservoir pressure monitoring. SenSym Model LX1820 0-150 psia transducers are used for all remaining channels. These strain-gauge based transducers have excellent temperature and drift characteristics. Each transducer is fully enclosed within a metal casting for noise immunity. Output voltage is linear with pressure for both models.

The pressure input to each gas transducer is mounted to the common port of a two-way solenoid valve. The normally open (n.o.) port is connected via a 1/8 inch nylon gas line to the pressure vessel being measured. The normally closed (n.c.) is connected to one of two pressure calibration manifolds. The LX1830 (0 - 300 psia) transducers are connected to the high pressure calibration manifold. This manifold is fitted with a pressure relief valve set at 300 psig. The input to this manifold is connected to a precision (1/4% accuracy) mechanical calibration gauge and precision regulator. This setup is used for calibration of the individual gas transducers at regular intervals. The LX1820 0-150 psia) transducers are connected to the low pressure calibration manifold. This manifold is fitted with a pressure relief valve set at 150 psig. The input to this manifold is connected to the same precision gauge and regulator set described above. The two calibration manifolds are isolated from each other by a pair of solenoid valves. A gas system schematic appears in Figure 5.1.

The solenoid valves are controlled by a three-position switch located near the calibration gauge. In the center position all solenoid valves are de-energized and their respective transducers connected to the various simulator gas volumes. This is the normal operating position. The other two positions, labeled "low calibrate" and "high calibrate" activate the solenoid valves associated with the low and high calibration manifolds respectively. A light is provided to aid in reading the calibration gauge.

The electrical outputs of the transducers are routed to a small card cage located elsewhere in the gas Hoffman box. Here the signals are aggressively filtered using a R-L-C network. High surge current diodes clamp each individual channel to a safe level during transient simulator oper-

ation. These signal conditioning boards are interchangeable with those used in the CAMAC cabinet. The outputs of these signal conditioning boards are routed to a pair of bulkhead-mounted DB-25 connectors with built-in L-C network 2 MHz low pass filters. From the DB-25 connectors the signals are wired into the external 52 pin military connector. This rugged all metal shell connector ensures RFI/EMI tightness and years of service.

5.2.2 Gas Pressure Signal Transmission to CAMAC.

The individual gas transducer signals make their way from the gas Hoffman box to the Marx junction Hoffman box (located under the Marx) via their respective twisted pairs. Here they are broken out to terminal strips. The signals make their way, via twisted pair overall shield cable contained in EMT conduit, to the machine disconnect box located near the simulator coaxial disconnect panel. Here they are again broken out into terminal strips. From the machine disconnect box they make their way directly to the CAMAC cabinet via twisted cable pair in an overall shield and terminated in MS connectors. See Section 5.8 for additional information on the signal transmission hardware.

5.2.3 Gas Pressure Measurement CAMAC Hardware.

The gas pressure signals are conditioned and filtered through the analog channel system described in Section 5.9. They are then routed to CAMAC junction chassis "B" (analog junction chassis). From there they are routed to CAMAC LeCroy Model LG8252 A to D converter modules. See Section 5.9.1 for greater detail on this system hardware.

5.3 MARX CHARGING MONITORING SYSTEM HARDWARE DESCRIPTION.

This section covers the main Marx charging voltage and current monitoring system hardware installed for the MMC system.

The Marx charging monitors allow accurate remote measuring of all voltages and currents during the simulator charging cycle. This capability allows for faster and more accurate simulator trouble-shooting of Marx related problems. Combined with the automated record keeping of the

MMC system this will enable future trend analysis of Marx related failures.

Section 5.3.1 covers the Marx charging voltage monitors. Section 5.3.2 covers the Marx charging current monitors. Section 5.3.3 details the routing of both types of signals to the control room/CAMAC cabinet, and Section 5.3.4 covers relevant CAMAC hardware details.

5.3.1 Marx Charge Voltage Monitors.

The four Aurora simulator Marx generators are charged using a bipolar 60 kV power supply. This means that 8 voltage parameters must be measured. To supplement the computer display, four analog meters were installed at the main operator's console. These meters show the total charge for each (plus and minus). In order to avoid ground-loops these meters require their own set of resistive monitors. Therefore sixteen resistive monitors were required.

The precision resistors chosen are of the metal film variety manufactured by Caddock. These 1% tolerance resistors have low temperature coefficients and excellent long-term drift characteristics. The primary divider impedance for all monitors is 800 MW. The division ratio is approximately 13600:1. Each 800 MW primary resistor is made up from four series 200 MW individual resistors. The monitors are located in the Marx charging disconnect tank provided as part of the multipulse task. Electrically the primary divider resistors are located across the Marx charging filter cap. This point is on the Marx side of the high voltage disconnect relays. This allows direct measurement of charge voltage droop prior to Marx erection. The tap-off resistors are located in the Marx charging junction box. This RFI/EMI tight Hoffman box is located near the Marx charging disconnect tank. The low side of each primary divider resistor is connected to a 12 volt varistor referenced to ground. This serves two functions. First, the varistor will clamp the transient spike occurring during simulator firing. Second it prevents the low side of the primary divider resistor rising above 12 volts if the tap-off resistor should fail or be disconnected.

The sixteen voltage signals are routed by individually shielded twisted pair to the 52 pin MS connector located on the lid of the Marx charging disconnect tank. See Section 5.3.3 for further details on voltage monitor signal routing/conditioning.

5.3.2 Marx Charging Current Monitors.

An active monitoring system was implemented because existing electrical and physical restraints precluded various preferable passive methods. The current transducers selected are magnetic amplifier based devices from American Active Controls. These transducers measure the current flowing through a conductor by measuring the magnetic field produced. There are eight transducers installed in the Marx charging disconnect tank. They are organized into four pairs, one for each Marx. Each pair measures its Marx's positive and negative charging currents during the entire charging cycle. The current monitors are located on the HVPS side of the disconnect switches to isolate them from transients during Marx erection.

Transducer output is 0-10 VDC (plus offset) corresponding to a full scale range of 500 mA. Offset voltages are individually calibrated for each transducer. Overall accuracy is 5% with reproducibility in the 2% range.

The environment within the Marx charging disconnect tank is severely unkind to active electronic components. High EMI/RFI fields, large pulsed currents, and the presence of high voltage all contribute to the problem. In addition, the Diala oil attacks many standard electronic parts. These factors required both the modification and repackaging of the magnetic amplifier transducers.

The final configuration incorporated the following modifications to the transducers. The modifications were undertaken with the knowledge and assistance of the manufacturer.

- The on-board AC power supplies were disconnected and externally supplied, filtered DC substituted for circuit operation.
- The transducers were repackaged in RFI tight aluminum enclosures. These enclosures have two isolated compartments. The upper compartment houses several protection circuits and serves as the entry point for all connections (other than the high voltage lead being measured). Signals and DC supply voltage enter here via a 7 pin military screw shell connector. Signals and the DC supply voltage are fed from the upper to lower compartments

through C-L-C low pass filters. The lower compartment houses the transducer, complete with its original metal case for double isolation.

- Various nonlinear components were added to all wires entering both compartments to limit voltage levels.
- Additional R-C-L filtering was incorporated on all lines to augment the commercial C-L-C filters.
- A relay, located in the upper compartment, automatically disconnects the transducer before Marx erection.

These changes along with the use of custom manufactured triple shielded twisted pair cable for interconnection to the 52 pin connector on the disconnect tank lid have resulted in a reliable current measuring system. The +18 VDC supply used for transducer power is located in an existing box located on the disconnect tank lid. This supply is automatically activated by the Marx disconnect relay control signals. See Section 5.3.3 for details on signal routing.

5.3.3 Marx Charging Signal Transmission to CA-MAC.

The Marx charging voltage and current signals are transported from the 52 pin MS connector located on the lid of the Marx charging disconnect tank to the Marx charging Hoffman box via overall shield 26 twisted pair cable. Both ends of this cable are terminated in screw shell military connectors for RFI immunity and long service.

Upon entry of the Marx charging Hoffman box, the signals are routed through 2 MHz low pass filters and onto a small card cage located inside the Hoffman box. Here the signals are filtered again using a discrete R-L-C network. Clamping diodes limit signal voltages to + 12 VDC for downstream circuit protection. The MMC Marx voltage monitor tap-off resistors are located on these signal conditioning cards for easy service. Other than the addition of the previously mentioned tap-off resistors, these cards are interchangeable with those used elsewhere in the system. The signals are then routed through another 2 MHz low pass filter and onto another 52 pin military connector.

After exiting the Marx charging Hoffman box the signals are routed to the Marx junction Hoffman

box (located under the Marx) using overall shield twisted pair cable. Here the individual signals are broken out into terminal strips for easy troubleshooting/monitoring. The signals make their way, via twisted pair overall shield cable contained in EMT conduit, to the machine disconnect box located near the simulator coaxial disconnect panel. Here they are again broken out into terminal strips. From the machine disconnect box the MMC signals make their way directly to the CAMAC cabinet via overall shield twisted cable terminated in MS connectors. The signals driving the charge voltage meters are routed to the auxiliary 19 inch rack located next to the operator's console. From there they are routed to the meters. See Section 5.8 for additional information on the signal transmission hardware.

5.3.4 Marx Charging CAMAC Hardware.

The Marx charging signals are conditioned and filtered through the analog channel system described in Section 5.9.1. They are then routed to CAMAC junction chassis "B" (analog junction chassis). From there they are routed to a CAMAC LeCroy Model 8212 simultaneous scanning A to D converter. Simultaneous sampling is necessary for accurate integration of Marx voltage and current data. See Section 5.9 for greater detail on this system hardware.

5.4 BLUMLEIN OIL SWITCH POSITION MONITORING HARDWARE.

This section covers the Blumlein oil switch position monitoring system hardware. Sections 5.4.1, 5.4.2, 5.4.3 and 5.4.4 cover transducer, signal transmission, digital readouts, and CAMAC hardware details respectively.

The Blumlein switch monitoring system allows easier and more accurate position measurement of the Aurora Blumlein oil switch electrodes. The existing measurement and control hardware was left intact and operational. This measurement system was simply placed in parallel with the existing one. The measurement method selected is designed for years of service with regular calibration as the only maintenance required. Two types of readouts are provided.

The MMC computer readout features automatic recording of electrode switch position for every shot. Also, by the use of the tolerance feature, the current position can be checked against a stored nominal value to prevent simulator operation with incorrect switch spacings.

A second display mode is provided in the form of eight digital readouts, one for each electrode being measured. All readouts are calibrated in inches. Overall system accuracy is limited by the cumulative mechanical, hydraulic, and electrical tolerances; the hydraulic system being the dominate factor. Positional accuracy of the trigger electrode and main gap spacings are approximately $\pm .125$ inches and $\pm .250$ inches respectively. This represents about 1-2% of full scale. The long term accuracy of the main gap reading is dependent on no slip occurring between the Blumlein and its supporting straps. It should be noted that the previous measurement method also suffers from this problem.

5.4.1 Blumlein Oil Switch Position Transducers and Support Electronics.

The transducers selected are precision linear potentiometers. This approach avoided any active electronics exposed to high RFI/EMI environments present under the Marx. The choice of linear over multi-turn potentiometers came from previous experience of the Aurora operations staff using the existing measurement hardware. The transducers are fitted with screw shell military multipin connectors for durability and noise immunity. The sealed case design allows for long service in industrial environments with reasonable exposure to oil, dirt, etc.

The eight potentiometers, four for trigger electrodes and four for main gaps, are mechanically attached to the slave cylinders of the existing Blumlein switch hydraulic system. Thus their accuracy depends on the condition of that system.

The linear potentiometers are (electrically) placed across a precision ± 10 VDC source. Thus the potential measured at the pot's wiper will be a 0-10 VDC indication of the spacing in question. The precision voltage source is located in the Marx junction box. Various protection and filtering elements are incorporated to protect the supply. The voltage source and wiper signals are transported to the individual linear pots via overall shielded multiconductor cable.

5.4.2 Blumlein Oil Switch Position Signal Transmission to Control Room.

Once inside the Marx junction box the individual position signals are broken out into terminal strips for easy troubleshooting/monitoring. The signals make their way, via twisted pairs in an overall shielded cable contained in EMT conduit, to the machine disconnect box located near the simula-

tor coaxial disconnect panel. Here they are again broken out into terminal strips. From the machine disconnect box the MMC signals make their way directly to the CAMAC cabinet via overall shield twisted pair cable terminated in MS connectors. The signals driving the digital position readouts are routed to the auxiliary 19 inch rack located next to the operator's console. See Section 5.8 for additional information on the signal transmission hardware.

5.4.3 Blumlein Oil Switch Position Digital Readouts.

The eight electrode switch positions (trigger and main gap for each of the four Blumleins) are displayed using eight digital panel meters in the PSI control rack. The meters selected are micro-processor based units from DigiTec (Model 2820A opt F). This type of meter features self-calibration, offset and scale factors, and one part in 104 resolution. These features allow actual oil switch gap spacings in inches to be displayed. Entry of new calibration factors or offsets is done via front panel switches. Transient protection circuitry was incorporated for meter protection.

5.4.4 Blumlein Oil Switch CAMAC Hardware Description.

The Blumlein oil switch position signals are conditioned and filtered through the analog channel system described in Section 5.9. They are then routed to CAMAC junction chassis "B" (analog junction chassis). From there they are routed to CAMAC LeCroy Model LG8252 A to D converter modules. See Section 5.9 for greater detail on this system hardware.

5.5 VACUUM MONITORING HARDWARE DESCRIPTION.

High vacuum transducers and remote readout gauges were provided for all four output tubes and their associated anode regions. The gauges selected are of the cold cathode variety and exhibit an operational range of 1×10^{-3} to 1×10^{-7} Torr. This type of gauge was selected for its increased immunity to high EMI/ RFI/X-ray levels generated during simulator operation. Cold cathode gauge transducers can be located several hundred feet from their displays unlike most ion gauges. This feature allows the readout electronics to be located in the control room. An interface board allows the MMC system to monitor vacuum in all eight locations.

Section 5.5.1 covers vacuum transducers and readouts, Section 5.5.2 outlines signal transmission hardware, and Section 5.5.3 covers CAMAC hardware.

5.5.1 Vacuum Transducers and Readouts.

Cold cathode vacuum transducers (Varian Model 524) were used in all eight monitoring locations. These gauge tubes, because of their geometry, tend to pick up much less noise than conventional ion gauges. In addition they are more tolerant to contamination than most ion gauge tubes.

The vacuum readouts are Varian Model 860 with dual setpoints. The setpoint feature allows future use as an interlock by the Aurora staff. Additional filtering elements were added to the gauge tube outputs for increased noise immunity. The chart recorder outputs were electrically conditioned using a custom interface board. This allows monitoring by the MMC/CAMAC system. The readouts are organized to two individual four-channel rack mounted units. One for the tube and one for the anode regions. These chassis are located in the PSI control rack which is placed within easy sight of the operator's console.

5.5.2 Vacuum Signal Transmission to Control Room/CAMAC.

The eight vacuum transducers are connected to their respective readouts via solid poly RG-59 (75 W) cable. Since the excitation voltage of the cold cathode gauge tubes is between 2 and 3 kV, MHV type connectors were used.

5.5.3 Vacuum Measurement CAMAC Hardware.

The vacuum signals are conditioned and filtered through the analog channel system described in Section 5.9.1. They are then routed to CAMAC junction chassis "B" (analog junction chassis). From there they are routed to CAMAC LeCroy Model LG8252 A to D converter modules. See Section 5.9 for greater detail on this system hardware.

5.6 TAG AND TRIGGER MARX CHARGE VOLTAGE MONITORS.

The TAG and trigger Marx charge voltages are recorded by MMC using the existing cables and monitors. Signals are tapped off at the operators console using circuit cards attached to the back of the corresponding channel's analog meter. The signal is then routed to CAMAC and conditioned as per Section 5.9.1. After passing

through junction chassis "B", the signals are routed to LeCroy LG8252 A to D converters.

5.7 DIGITAL/LOGICAL SIGNALS.

This section covers the Digital (or logical) I/O hardware provided as part of the MMC task. While this hardware is currently only utilized for synchronization of the MMC computer and the present simulator control system, it is intended to allow computer monitoring and control of virtually any compatible device required. Forty-eight digital input and 96 output channels are provided. The signal conditioning hardware for an additional 48 input and output channels are also provided. Section 5.7.1 covers the input channels, and Section 5.7.2 covers the output channels.

5.7.1 Digital Input Channels.

The 48 digital inputs are available at the rear of the PSI control rack. Each channel is considered TRUE or ON when connected to ground. Conversely, when open, a channel is considered FALSE or OFF. The individual inputs are conditioned as per Section 5.8.1 and routed to a Kinetic Systems Model 3472 input module via junction chassis "A". Signal conditioning hardware and terminal positions in junction chassis "A" for an additional 48 channels are provided.

5.7.2 Digital Output Channels.

The 96 digital outputs are utilized by means of using two 48 channel "OUTPUT REGISTER BUFFER" rack mounted chassis. The individual channels are configured as normally open (convertible to n.c.) contacts rated at 1 amp. These contacts are available at the rear of the chassis on two 52 pin MS connectors. A LED indicates the state of each output channel for easy monitoring by the system operator.

Each 48 channel buffer chassis is connected to the CAMAC cabinet via a 52 conductor cable terminated with MS connectors. Each control signal is filtered as per Section 5.8.1 and routed to a Kinetic Systems Model 3072 output register module via junction chassis "A". Signal conditioning hardware and terminal positions for an additional 48 channels are provided.

5.8 SIGNAL TRANSMISSION SYSTEM DESCRIPTION.

Various slow analog voltages are transported from their source points on the simulator to the

control room by way of the signal transmission system. A block diagram (Figure 5.2) illustrates how the system is organized.

The simulator gas pressures, charging currents/voltages and oil switch electrode position signals are all gathered from the area under the Marx tank and routed to the Marx junction Hoffman box. Here the signals are broken out into terminal strips for easy monitoring and/or modification.

Between the Marx junction Hoffman box and the machine disconnect Hoffman box a set of two four-inch inside diameter EMT conduits has been installed. Inside one of these conduits, four shielded 26 pair cables carry the signals between the two Hoffman boxes previously mentioned. The four cables are allocated for gas pressures, Marx charging, oil switch position and miscellaneous monitoring and control.

Inside the machine disconnect box, signals are again broken out into terminal strips. They are then routed to MS connectors located on the exterior of the enclosure. It is from this point that the simulator may be disconnected to allow "roll-back" for vacuum insulator service.

From the MS connectors on the disconnect box the signals make their way, via 26 pair shielded cable, to the control room. The miscellaneous signal cable goes directly to the PSI control rack. The other three cables go to the CAMAC cabinet #1. An additional 26 pair cable carries signals between the CAMAC cabinet and the PSI rack. Between the PSI rack and the operator's console yet another 26 pair cable is used for interface and TAG/trigger Marx signals.

5.9 SLOW SIGNAL CAMAC CABINET (#1) DESCRIPTION.

The slow signal cabinet (#1) houses all the signal conditioning, routing, and CAMAC hardware required by the slow signal subsystem of MMC. In addition, the photodiode transient recorder used by the fast signal subsystem is located here due to space restrictions in CAMAC cabinet #2. A block diagram of CAMAC cabinet #1 is shown in Figure 5.3.

Slow signals from the simulator enter the cabinet via external MS connectors located in the lower portion of the rear panel. Here any current flowing on the shield of the data cables is "stripped-off" and flows on the exterior of the enclosure. It is vital that this not be compromised because elec-

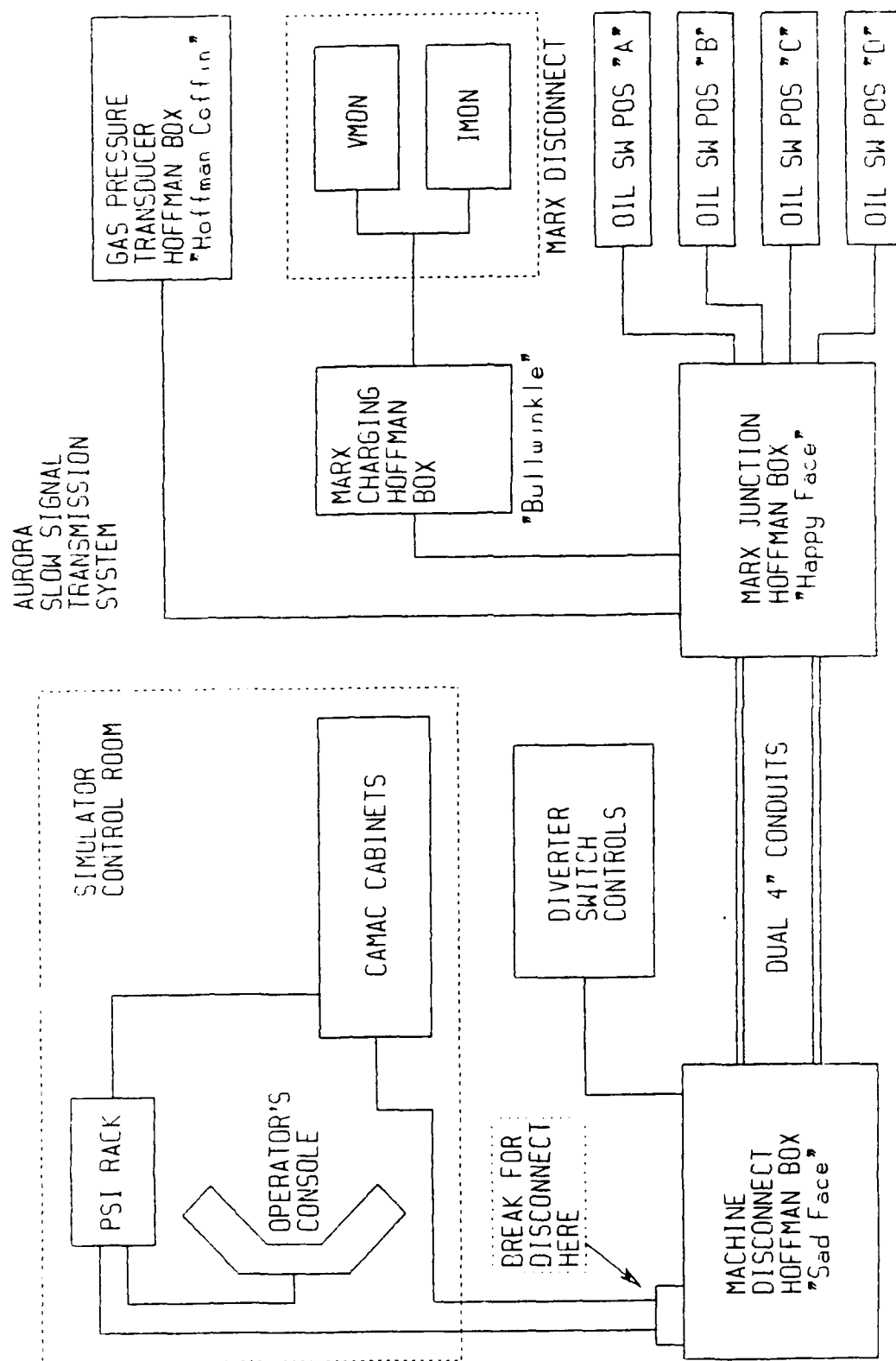


Figure 5.2. Aurora slow signal transmission system.

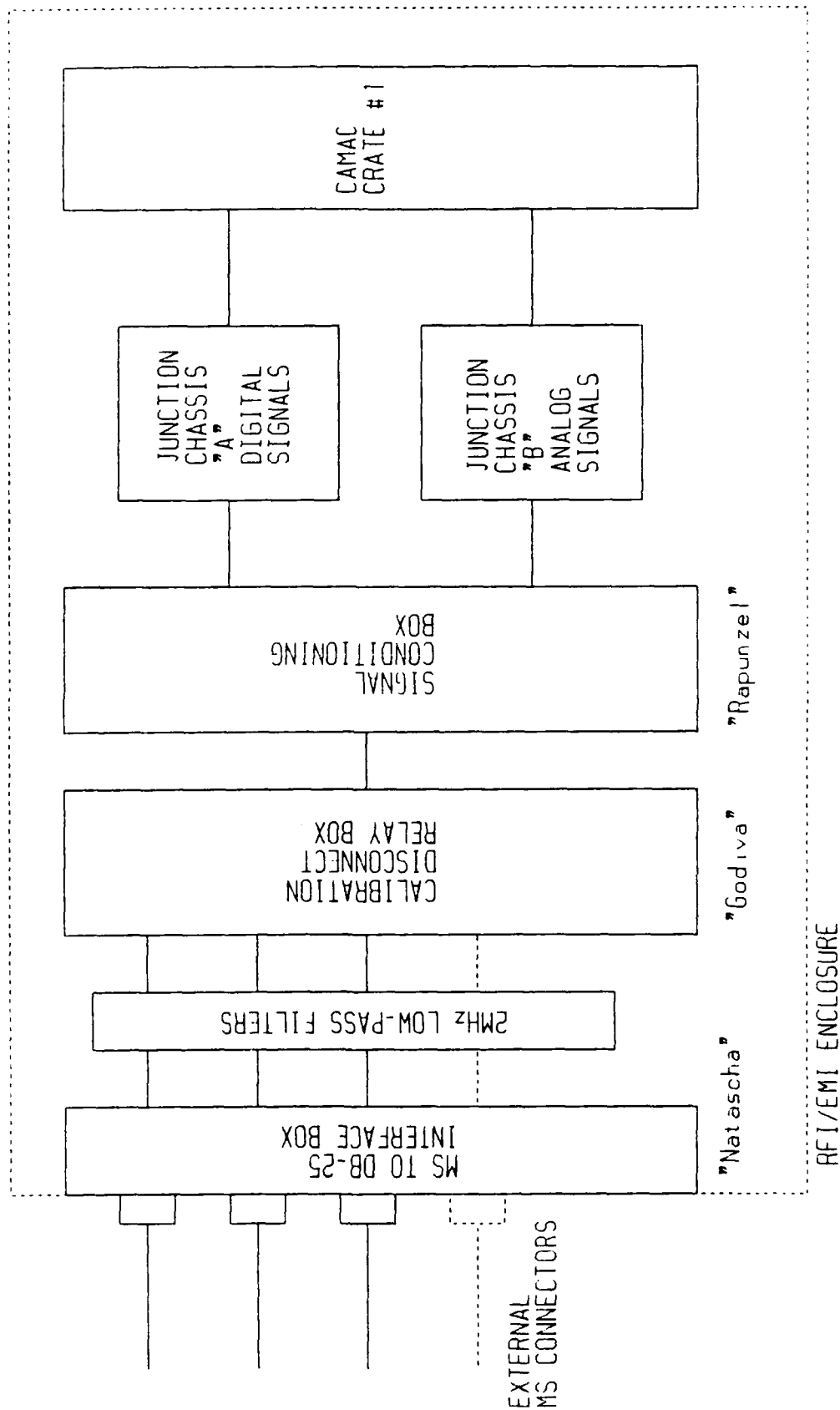


Figure 5.3. Aurora CAMAC cabinet #1 block diagram.

trical noise with damage to the CAMAC hardware could result!

Upon entering the cabinet the signals are routed through an RFI tight interface box where they are reconfigured to DB-25 connector format. They exit this box in shielded cables terminated in DB-25 connectors.

The signals are then routed through 2 MHz low-pass filters incorporated into DB-25 compatible connectors and into the calibration disconnect relay box. Each analog signal is then routed through a SPDT relay contact. These contacts, when energized, reconnect each CAMAC A to D input from its respective signal to a calibration voltage buss. This allows CAMAC module calibrations to be performed in-situ. The control for this feature is located on the front panel of junction chassis "A". Digital signals simply pass through the calibration disconnect relay box. All signals are next passed through to the signal conditioning box via two 2 inch conduits.

While in the signal conditioning box each channel is filtered and voltage limited to protect the CAMAC hardware. Details of this hardware are outlined in the Section 5.9.1. The conditioned signals exit this box through DB-25 connectors into shielded cables.

From this point the signals are separated into two groups, digital and analog. The digital signals are routed to junction chassis "A" and the analog signals routed to junction chassis "B". See Section 5.9.2 for further details on these two junction chassis.

Each signal upon exiting their respective junction chassis is then routed directly to its CAMAC input.

5.9.1 Signal Conditioning Hardware.

This section covers the signal conditioning circuitry and associated hardware used for all slow data channels within CAMAC cabinet #1.

All slow channels (digital and analog) are passed through a 2 MHz low-pass filter network upon entering the calibration disconnect relay box. This prevents high frequency noise from penetrating further into the CAMAC cabinet.

Within the signal conditioning box the digital and analog signals are routed to separate card cages

containing their respective filter/limiting boards. The signal conditioning circuits for both analog and digital channels are placed on ten channel cards which are removable for easy service.

The analog signal conditioning circuit schematic is shown in Figure 5.4. An R-L-C filter network coupled with diode clamping elements was selected. The clamping circuit limits incoming voltage levels to + 12 volts. The R-L-C network effectively filters incoming signals without limiting response time. A 33 KW grounding resistor provides a reference in case of open circuit inputs. This analog filter board is the same design as that used in the gas and Marx Hoffman boxes. All three boards are interchangeable.

The digital signal conditioning circuit schematic is shown in Figure 5.5. An R-C filter network coupled with diode clamping was selected. The clamping circuit limits incoming voltages to between 0 and +24 VDC. The aggressive R-C network effectively blocks transients from damaging CAMAC hardware.

5.9.2 Junction Interconnect Chassis.

The two CAMAC junction chassis ("A" and "B") serve as cross-connection points for digital and analog signal types respectively. This allows easy reconfiguration of individual signal channels to CAMAC input channels. All signals enter the two channels via DB-25 connectors on their rear panels. From this point the individual channels are broken out into terminal blocks.

Junction chassis "A" (which serves digital channels) has all its output connections on the rear panel. This was done because the CAMAC I/O registers selected by HDL also have rear panel connections. These output connections are also broken out into terminal blocks similarly to the input outlined earlier. Hardware programming of inputs to outputs is thus accomplished simply by terminal strip jumper wires.

There are several front panel controls on the "A" junction chassis (Figure 5.6). The "OIL SWITCH CONTROL ENABLE" and "DIVERter SWITCH CONTROL ENABLE" switches are not currently implemented and intended for expansion of MMC for control of the two switches implied. The "D.C. CHANNEL CALIBRATE" switch and the "CALIBRATION VOLTAGE INPUT" banana jack assemblies allow control of the calibration disconnect relay circuitry outlined earlier in Section 5.9.

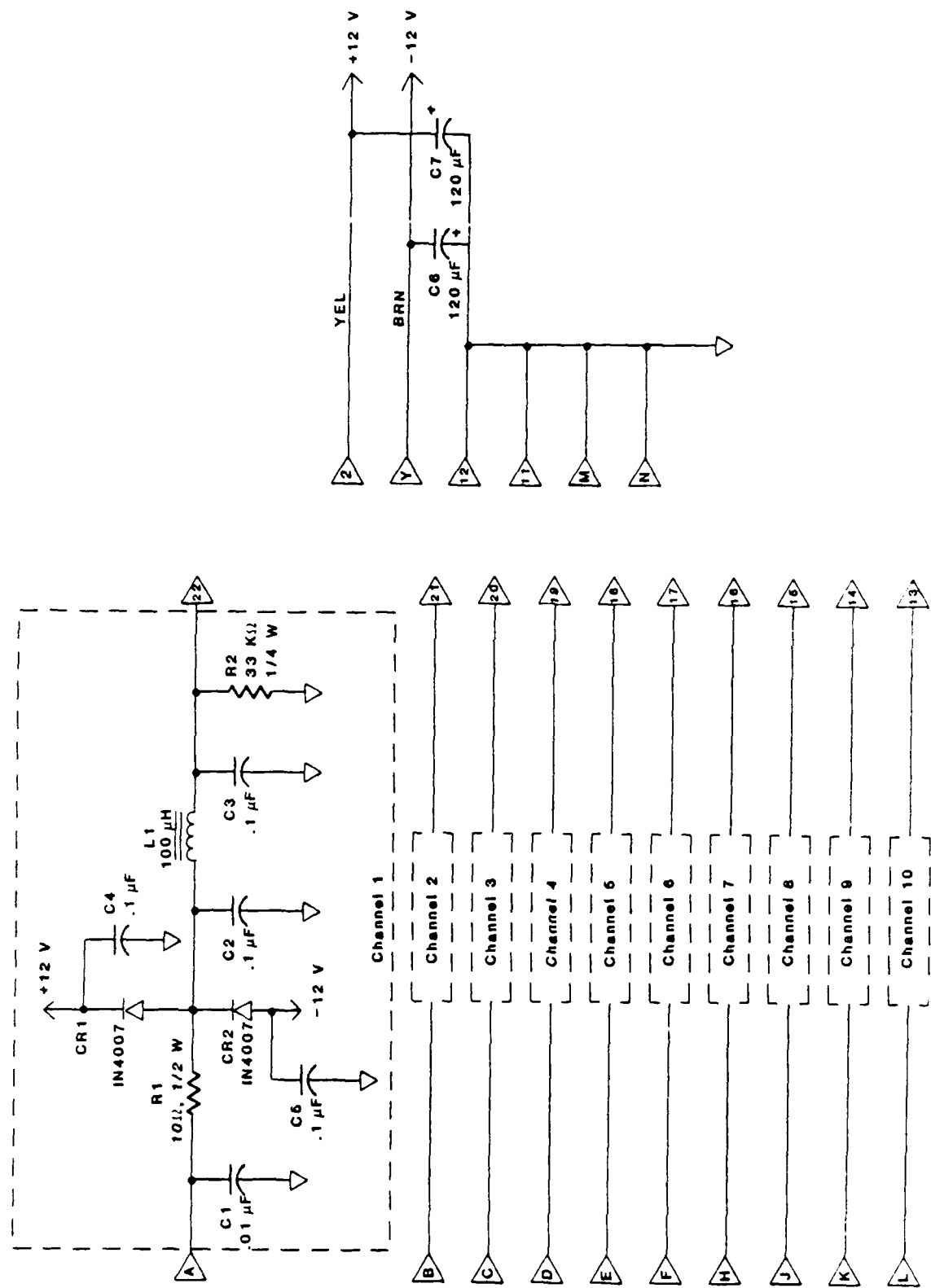


Figure 5.4. Aurora slow analog signal conditioning board schematic.

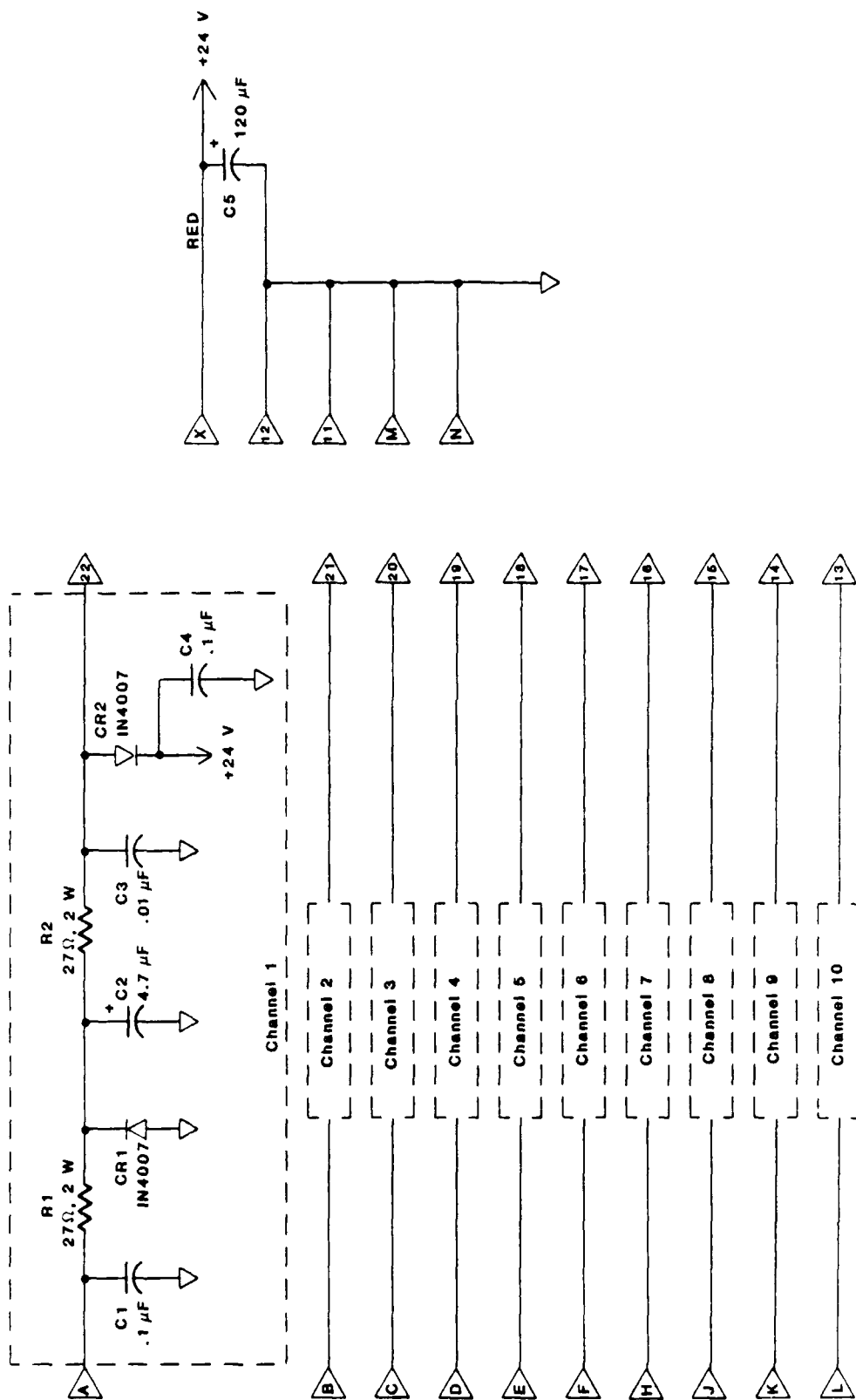
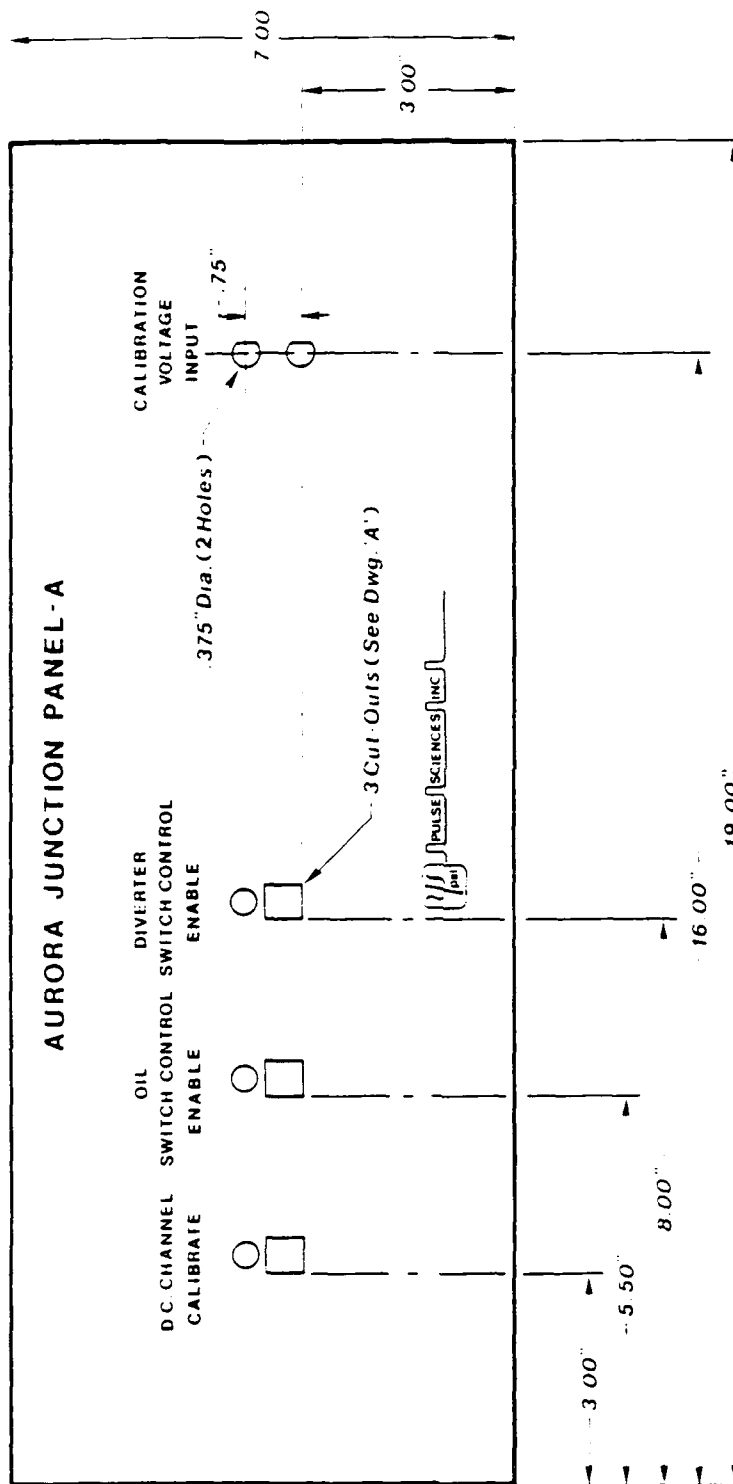


Figure 5.5. Aurora input/output register filter board schematic.



LETTERING HEIGHT: AURORA JUNCTION PANEL-A (1.31) ALL OTHERS (1.25)

PAINT: POLARIS MODULAR IVORY, FILL ENGRAVING WITH BLACK

DRAWING TITLE: AURORA JUNCTION PANEL A

DRAWN BY: MERED G HETNER ON JUNE 19, 1986

Figure 5.6. Junction A chassis.

Junction chassis "B" (which serves analog channels) has all of its outputs located on the front panel. The six DC-37 connectors are intended to service LeCroy LG8252 A to D converter modules. Two positions are required for each LG8252. Two spare connectors are provided allowing the addition of another LG8252 for future

expansion. The 35 Lemo two-pin connectors service the LeCroy 8212 scanning A to D converter. Both types of output connections are also broken out into terminal blocks similarly to the input outlined earlier. Hardware programming of inputs to outputs is thus accomplished simply by terminal strip jumper wires.

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